W. B. No. 713

U. S. DEPARTMENT OF AGRICULTURE

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CHARLES F. MARVIN, Chief

MONTHLY WEATHER REVIEW

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INTRODUCTION.

The MONTHLY WEATHER REVIEW contains (1) meteorological contributions, and bibliography including seismology; (2) an interpretative summary and charts of the weather of the month in the United States and on the adjacent oceans; and (3) climatological and seismological tables, dealing with the weather and earthquakes of the month.

The contributions are principally as follows: (*a*) Results of the observational or research work in meteorology carried on in the United States or other parts of the world, in the Weather Bureau, at universities, at research institutes, or by individuals; (*b*) abstracts or reviews of important meteorological papers and books; and (*c*) notes. In each issue of the REVIEW reviews, abstracts, and notes are grouped by subjects, roughly, in the following order: General work, observations, and reductions, physical properties of the atmosphere, temperature, pressure, wind, moisture weather; applications of meteorology, climatology, and seismology.

The Weather Bureau desires that the MONTHLY WEATHER REVIEW shall be a medium of publication for contributions within its field, but **the publication of contributions is not to be construed as official approval of the views expressed.**

The partly annotated bibliography of current publications is prepared in the Weather Bureau Library. *Persons or institutions receiving Weather Bureau publications free should send in exchange a copy of anything they may publish bearing upon meteorology, addressed "Library U. S. Weather Bureau, Washington, D. C.,"* in order that the monthly list of current works on meteorology and seismology may be as complete as possible. Similar contributions from others will be welcome. Bibliographies of selected subjects are published from time to time in the REVIEW OF SUPPLEMENTS.

The section of the weather of the month contains (1) an interpretative discussions of the weather of North America and adjacent oceans and some notes on the weather in other parts of the world; (2) details of the weather of the month in the United States; and (3) brief discussions of weather warnings, rivers and floods, and weather and crops. There are illustrative charts. The climatological tables comprise summaries of the weather and excessive precipitation data for about 210 stations in the United States, and summaries of the weather observed at about 30 Canadian stations.

It is hoped that the meteorological data hitherto contributed by numerous independent services will continue as in the past. Our thanks are due especially to the directors and superintendents of the following:

- The Meteorological Service of the Dominion of Canada.
- Meteorological and Seismological Service of Mexico.
- The Meteorological Service of Cuba.
- The Meteorological Observatory of Belen College, Habana.
- The Government Meteorological Office of Jamaica
- The Meteorological Service of the Azores.
- The Meteorological Office, London.
- The Danish Meteorological Institute.
- The Physical Central Observatory, Petrograd.
- The Philippine Weather Bureau.

The seismological tables contain, in a form internationally agreed on, the earthquakes recorded on seismographs in North and Central America. Dispatches on earthquakes felt in all parts of the world are published also.

Since it is important to have as the name of the month appearing on the cover of the REVIEW that of the period covered by the weather discussions and tables rather than that of the month of issue, the REVIEW for a given month does not appear until about the end of the second month following.

SUPPLEMENTS, containing kite observations, and others containing monographs or specialized groups of papers, are published from time to time.

NOTES TO CONTRIBUTORS.

Authors are requested to accompany their papers submitted for publication with a brief opening synopsis. When an article deals with more than one subject—as, for example, a method of measurement, some experimental results and a theory—each subject should be summarized in a *separate paragraph*, with a title which clearly describes it.

When illustrations accompany an article submitted for publication in the MONTHLY WEATHER REVIEW, the places where they should appear in the text should be indicated, and legends or titles for them should be inserted just after the end of the article. As far as practicable the illustrations when accompanied by their legends should be self-explanatory—i. e., the data on them should leave no doubt of what they are intended to convey.

BACK NUMBERS OF THE REVIEW WANTED.

The Weather Bureau has not enough of the following numbers of the MONTHLY WEATHER REVIEW to meet even urgent requests for filling up files at institutions where the REVIEW is constantly being referred to. The return of any of these or of any 1919 or 1920 issues, especially November, 1919, will be greatly appreciated. The attached addressed franked slip may be used for this purpose, or one may be had on application to Chief, U. S. Weather Bureau, Washington, D. C.

- 1914: January, February, March, April, September, October, December.
- 1915: May, June, July, August.
- 1916: January, August.
- 1917: June.
- 1918: February, September.
- 1919: Any issue, especially November.
- 1920: Any issue, especially January.
- SUPPLEMENT, No. 3.

MONTHLY WEATHER REVIEW

CHARLES F. BROOKS, Editor.

VOL. 48, No. 6.
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RELATION BETWEEN THE ANNUAL PRECIPITATION AND THE NUMBER OF HEAD OF STOCK GRAZED PER SQUARE MILE.

By J. WARREN SMITH, Meteorologist.

(Washington, D. C., June 30, 1920.)

SYNOPSIS.

In the Great Plains States the relation between the annual precipitation and the number of head of stock that can be grazed per square mile can be fairly well established, the possible number decreasing with fair uniformity from east to west with the decreasing annual rainfall. The number grazed in Oklahoma and Texas is close to 50 per square mile where the rainfall is between 25 and 35 inches and about 40 where the rainfall is from 15 to 25 inches.

In the Great Plains States north of Oklahoma where feeding is necessary during the wintertime and where the rate of evaporation is less in the summer months, the grazing rate averages close to 20 where the rainfall is between 10 and 15 inches, nearly 40 where it is from 15 to 20 inches, and nearly 80 where it is 20 to 25 inches. The ratio rises at a faster rate with heavier rainfall.

In all the Rocky Mountain region it becomes more difficult to establish a ratio between the annual precipitation and rate of grazing because of seasonal distribution of precipitation, temperature variations, the topography, soil, evaporation, snow cover, nature of the vegetation, and differences in the length of the grazing period. In the central and upper Rockies the grazing rate is slightly greater with small rainfall amounts than farther east because of the shorter grazing period, but less than in the Great Plains with heavier precipitation because of the relatively less grazing areas in the higher mountains where the greatest precipitation occurs.

In a study of the climatic control of Australian production [1] the following statement appears:

> As regards the three commodities under discussion (wheat, cattle, and sheep), the chief control is undoubtedly that of rainfall. This affects absolutely the distribution of wheat and notably that of cattle and sheep. However, although it is true that no cattle or sheep are found in the desert portion of Australia, yet the flocks and herds range from regions with 60-inch rainfall to those with 6 inches, implying a considerable range of adaptability on the part of the animals concerned. Yet as regards the more important sheep and cattle districts, the rainfall will be shown to define fairly accurately those areas where the pastoral industry seems to flourish best. Moreover, the same isohyets do not affect sheep and cattle equally, and this is another point which will be demonstrated in the maps.
>
> The temperature factor is very important in two of the industries. While cattle are almost ubiquitous and thrive even in the far north and far west, the hot country—or, more exactly, the tropical vegetation—does not appear to suit sheep so well as do the conditions in the cooler and drier regions to the south. The northern limits of the wheat belts are undoubtedly controlled by the increase in temperature.

In Australia, while large numbers of cattle are grazed where the average annual rainfall is between 10 and 20 inches, the best district has a rainfall of 20 to 40 inches a year. Dr. Taylor states that in western Australia the districts having a rainfall of 9 to 12 inches should support 4 cattle to the square mile, while those with a rainfall of 20 to 40 inches should have over 10 to the square mile. In Queensland, only 2 to 3 should be grazed where the rainfall is less than 10 inches.

The sheep occupy the warm inland drier belt and the cattle the wetter coastal regions. The optimum district for sheep is where the rainfall is 20 to 30 inches, except in Queensland where it is 15 to 20 inches. In Queensland where the rainfall is between 10 and 30 inches, 100 sheep to the square mile are grazed. In south Australia the 7-inch isohyet divides the districts of more than 10 and less than 10 sheep to the square mile.

In New South Wales, west of the divide, where the rainfall is between 20 and 30 inches, 250 sheep are grazed to the square mile; where it is between 10 and 20 inches 100, and where under 10 inches only 40 to the square mile on an average. In Victoria the optimum sheep district is where the rainfall is between 20 and 30 inches, while the 15-inch isohyet is the western limit of 100 to the square mile. In Tasmania the principal sheep grazing regions have an average rainfall of 20 to 30 inches.

It is well known in Europe that 1 acre of really good pasture land will support a cow, although in general it is customary to allow 4 acres. It is considered there that where more than 4 acres is necessary to support one cow the pasture should be devoted to sheep.

In the United States, the stock capacity of pastures and ranges depends not only upon the annual precipitation but on its seasonal distribution, as well as on the evaporation, snow cover, and the length of the grazing period, the last three depending largely upon the temperature.*

On the irrigated lands of the Northwest the stock-carrying capacity of 1 acre of well-established pasture should be not less than 2 cows, or their equivalent in other live stock, under favorable conditions and with proper care.[2] This is at the rate of 1.280 per section or square mile, but it is under irrigation in well-established pasture that has been given the best of care.

In the bluegrass region of central and eastern Kentucky and adjoining districts, 22 of the best pasture fields, totaling 4,237 acres, grazed 1,328 head of cattle, or an average of 3.2 acres per head, equivalent to 200 per square mile. These were the best pastures and do not include steep wooded mountains or rocky lands.[3] The average annual rainfall in this region is from 40 to over 50 inches, and the winters are mild enough to allow for grazing most of the year.

On the bluegrass pastures in the eastern third of Kansas, where the average annual precipitation is between 30 and 40 inches, the practice is to allow about 4 acres to each steer, or at the rate of 160 steers to a square mile. In the western third of the State, where the precipitation averages from 16 to 20 inches, the usual allowance is 10 acres to the steer, or 64 to the section. In the central third of the State, where the rainfall is between 20 and 30 inches, the usual pasture lands graze between these two extremes of stock. Considerable roughage is fed in dry seasons and in the winter time.

[1] The climatic control of Australian Production, Griffith Taylor, Bulletin 11, Commonwealth Bureau of Meteorology, Melbourne, Australia.

*The topography, soil, and nature of the vegetation must also be taken into account.

[2] Irrigated pastures for northern reclamation projects, Bureau of Plant Industry; Bulletin issued July 26, 1916.

[3] The Grazing Industry of the Bluegrass Region, United States Department of Agriculture, Bulletin No. 397, Sept. 20, 1916.

In extreme eastern Nebraska, where the annual rainfall averages from 26 to 33 inches, from 426 to 640 cattle are grazed per section. In the central part of the southern border counties of Nebraska, where the rainfall varies from 25 to 20 inches from east to west, the number of acres required for each steer varies from 2.5 to 6, or from 256 to 107 can be grazed per square mile, the number per section decreasing westward with the rainfall.

In the Sand Hill region of central Nebraska, where the rainfall is from 18 to 22 inches a year, only from 43 to 50 head of cattle are grazed on a square mile of grazing land. In the national forest region of the Sand Hill district of western Nebraska the average head per square mile of grazing land is 50.

The conditions in Nebraska indicate that rainfall is not the only factor in determining the grazing capacity of the land, but that the character of the soil and the temperature are both important.

In the national forest area in South Dakota (District No. 2 of the Forest Service), where the grazing area is about 73 per cent of the total, 30 head are grazed to the square mile on the actual grazing land. The annual rainfall in most of this region is between 15 and 20 inches. This agrees well with the relation in other sections of the State, except that there is a much larger number of stock in proportion to the rainfall in the area of Jackson, Haakon, Lyman, and Stanley Counties in the central-southwest portion, probably due to the better shipping facilities. In general, in that State, where the annual precipitation is between 15 and 20 inches, the stock runs between 20 and 30 to the square mile.

The grazing period in the national forest area in South Dakota is about 6½ months.

In that part of western North Dakota west of the one hundredth meridian, where the annual precipitation is between 15 and 18 inches, the average number of acres for a 2-year-old steer or colt is 10, or 64 to the square mile. This varies from 43 to 128, depending upon the location.

In the Panhandle district of Texas, including 35 counties with a total area of 1,050 square miles, the average area required for each steer is 20 acres. This is at the rate of 32 per square mile. Soil conditions and cultivation reduce the fair to good grazing ground about one-third, thus making the actual grazing ground support close to 48 cattle to the square mile. The rainfall in this region is close to 20 inches, and nearly 70 per cent of the annual precipitation is received from April to September, inclusive. The evaporation in this region from a water surface is close to 45 inches a year, thus making the carrying capacity less than farther north, where the rainfall is the same.

From information obtainable in Oklahoma, it appears that for year-round pasturing on native sod 15 to 20 acres are required per head of cattle or horses and 2 to 2.5 acres per head of sheep or goats on the range lands of the northwestern counties. On the range lands of southwestern Oklahoma 12 to 15 acres are required per head of cattle or horses and 1½ to 2 acres per head of sheep or goats.

This is at the rate of 32 to 43 head of cattle per square mile where the rainfall varies between 15 and 25 inches and from 43 to 53 head where the rainfall is from 25 to 35 inches. Native pastures are grazed throughout the year in this State, with more or less feeding from December to March, depending upon the inclemency of the weather and the character of the preceding growing season.

In the Great Plains States, just discussed, the precipitation decreases with fair uniformity from east to west, so that large areas can be considered in determining the stock-carrying capacity of the ranges.

Over the great mountainous range States farther west, however, the precipitation is so variable within comparatively short distances, due largely to the topographic features, that a study of the relation of rainfall to grazing becomes much more difficult. The seasonal and yearly distribution of the precipitation is very variable also, and a range carrying a good stand of forage one season may be practically bare the next, due to a very light rainfall. Indeed, it is not uncommon to have a series of years with the rainfall materially less than the normal, or a year when from one-half to two-thirds of the total annual precipitation occurs in one month. A heavy rainfall will be followed by a rapid growth of forage, so that a wet month will be followed by a month or more of good feed.

In the central and lower Rocky Mountain States the stock graze at higher elevation in the summertime and are driven to the lower plains and plateaus in the winter. Close grazing during a season may reduce the carrying capacity about two-thirds.

About three-eighths of the grazing lands of New Mexico receive an average annual rainfall of from 10 to 15 inches, another three-eighths receive from 15 to 20 inches, while about one-eighth have over 20 inches and an equal amount less than 10 inches. Cattle are most numerous in the areas receiving from 15 to 20 inches and sheep are quite as numerous in the districts where the annual precipitation averages less than 15 inches.

The higher districts, with precipitation of 15 to 20 inches or more, are principally used for summer ranges, and stock are moved out at the approach of winter.

Over the plains and lower plateau districts where the annual rainfall averages 10 to 15 inches, some 30 to 40 acres are allowed for each head of cattle, horses, or mules, while 6 to 8 acres are allowed each head of sheep or goats. At higher altitudes, where the precipitation averages 15 to 20 inches, the allowance is 20 to 30 acres per head of cattle and 4 to 6 per head of sheep.

This is equal to 16 to 21 head of large stock per square mile with 10 to 15 inches of rainfall and 21 to 32 head where the rainfall averages 15 to 20 inches. These figures are only approximate, however, as the seasons are so variable. With a dry year such as occurred in 1917 and 1918, even 50 to 100 acres may not afford sufficient feed for one head of large stock, and at the lower elevations whole sections may be so barren that they can not be grazed at all.

In the Pecos Valley, in southeastern New Mexico, where the average rainfall is not over 15 inches, it is estimated that 12 head of cattle can be grazed per square mile if the rainfall is normally distributed; that is, about half of the total annual fall coming during the three summer months. In years with only 50 per cent of the normal precipitation the grazing capacity will be reduced nearly one-half. The following table gives a fair estimate of grazing in the Pecos Valley:

Rainfall.	Cattle per square mile.
Normal, 15 inches	12
50 per cent of normal, 7.5 inches	7
75 per cent of normal, 11.2 inches	10
125 per cent of normal, 18.8 inches	14
150 per cent of normal, 22.5 inches	16

In this region the above figures are also applicable to any month from April to November, inclusive; the number of cattle grazed in any month being dependent upon the precipitation of the preceding month. For example while there was more than the normal rainfall in 1916, two-thirds of the total fell in August. The grazing was very poor up to August but was excellent after that month.

Studies of grazing capacity, on the Jornada Range Reserve in southern New Mexico led to the conclusion that the grama grass range will support one cow on 20 to 30 acres, depending upon the acreage of poorer range types which occur within the grass type.[4]

These figures are computed on a yearlong basis, but with the understanding that the number of stock will be reduced to about one-half the yearly average during the season from July to October. The annual rainfall in this region is close to 8 inches.

There are two well-defined rainy seasons in Arizona, one in winter and the other in summer. It follows, therefore, that there are two well-established growing seasons, except at the high altitudes, above about 4,500 feet, where the winters are so cool as to prevent growth. At the lower altitudes a period of dry weather usually occurs in April, May and part of June, during which time growth ceases and the spring annuals dry up.

The seasonal distribution of the scanty rainfall, and the differences in soil, exposure, and altitude, all resulting in a variety of vegetation, makes it difficult to establish a ratio between the rainfall and the stock grazing in this State. The drier areas often support a variety of browse that has a high sustaining power for stock during periods of drought, while the higher ranges with a greater precipitation afford more succulent types of forage which do not stand periods of drought.

In general, however, the following table presents the relation between rainfall and cattle grazing in this State.

Annual rainfall.	Acres required per steer.	Cattle per square mile.
Less than 5 inches	Will not support stock	0
5 to 10 inches	From 150 acres near 5-inch isohyet to 40 acres near 10-inch isohyet	4 to 16
10 to 15 inches	40 to 32	16 to 20
15 to 20 inches	32	20
20 to 25 inches	30	21

The territory with an average annual precipitation of 20 inches or more is nearly all within the National Forests. The carrying capacity in this region is about 30 acres to each cow or steer, although in the most favorable location it may be as low as 20 acres. Horses require a little different type of range, and since they depend to a larger extent upon forage grasses, a greater area is necessary.

Before the dry period of 1891–1894 more than double the safe carrying capacity of the ranges was being grazed over a large part of this State. With this over-grazing and the general shortage of feed and water, 25 per cent to 50 per cent of the stock died during 1891–1894 in many locations.[5]

At the lower altitudes in Arizona where forage production is often scant, 60 to 75 acres should be allowed for each animal, and in addition some provision should be made for a supply of feed to assist in carrying stock through the occasional severe droughts. The writer of Bulletin No. 65 states further that on rather closely grazed bunch-grass ranges, 25 to 30 acres are necessary for each head of stock, and 15 to 20 acres on the better class of these ranges. Where possible, it has been found advantageous to graze stock on the lower winter ranges from February to June, and on the higher bunch-grass ranges during the remainder of the year.

Good grass foothill pastures of the Santa Rita Range Reserve in southern Arizona have furnished an average of 365 cow-days' feed annually over a period of years on an average of about 14 acres. Each year during the main growing season the number of stock was reduced about 30 per cent below the average for the year, to give vegetation a chance to grow. Otherwise grazing was yearlong. Utilization was closer than can be expected on open ranges.[6]

In Utah the summer grazing ranges are at the higher elevations and the period covered in July, August, and September. The winter snowfall in these summer-range districts is from 50 to 75 inches or more and has an important bearing on the amount of spring and early summer feed. The snow enables the stock, especially sheep, to feed away from running water, hence where the snowfall is normally small a larger acreage for each head must be provided for safety. For these reasons the summer-grazing districts carry many more stock to the square mile with the same annual rainfall, in this State and to the northward, than in the States farther south, and more than the winter ranges in this State.

There is an area in Rich and Cache Counties where there is a good range that requires only 5 acres to the steer during the three summer months, although the average annual rainfall is between 15 and 20 inches only. Other regions farther south with about the same rainfall, require only from 1 to 2 acres for each head of sheep for the summer months. In Piute and western Wayne Counties where the annual rainfall is less than 10 inches, and the snowfall is not so great it requires from 2 to 2.5 acres for each head of sheep. It is estimated in this State that a steer or horse requires about seven times as much territory as one sheep, although this ratio is variable and depends upon the character of the vegetation. The secretary of the National Wool Growers' Association says that about 700 pounds of sheep consume about as much feed as 840 pounds of steer.

If the acreage required for sheep is translated to cattle at a ratio of 1 to 7, we find that the summer ranges in Utah will support from 46 to 73 cattle per square mile during the three months, where the annual precipitation is from 15 to 20 inches or over; from 36 to 46 in parts of the area that receive from 10 inches or slightly less to 15 inches. In the winter range districts, based on the same ratio, a square mile will support from 7 to 10 cattle where the annual precipitation is from 5 to 10 inches, and 16 where it is between 10 and 15 inches. In some sections of the State the figures given above are for actual grazing land which may not be more than one-fourth of the total in the territory.

In the National Forest areas, particularly in Colorado and Wyoming, there is such a variation in the quality and quantity of the forage, as well as in the seasons and the distribution of the precipitation throughout the seasons, that a closely drawn ratio between rainfall and the number of head of stock possible per unit of area is subject to serious question.

Where lands are fenced and the number of stock on particular areas definitely controlled there may be a closer correlation possible. For example, in Lincoln

[4] Increased Cattle Production on Southwestern Ranges, United States Department of Agriculture, Bulletin 588, 1917.

[5] The Grazing Ranges of Arizona, Arizona Experiment Station, Bulletin No. 65, 1910.

[6] Range Management of the National Forests, United States Department of Agriculture, Bulletin 790, 1919.

County in eastern Colorado, it is considered that a section of grama grass land will carry about 50 head of cattle for about 7 months in the average season.

In the National Forest lands in Colorado, however, the average head of stock per square mile of grazing land, in terms of cattle, is 47. The average grazing season for cattle and horses is 6 months and the average sheep season is about 3 months. The ratio between sheep and cattle is 5 to 1. The area of National Forests in Colorado is 14,988,190 acres and about 60 per cent is grazing land. The grazing stock consists of 421,015 cattle and horses and 1,177,190 sheep and goats. The annual precipitation is from 20 to 30 inches in the higher mountains in Colorado and from 15 to 20 inches in the foothills of the forest reservations.

The National Forest lands in District No. 2 in Wyoming cover some 4,019,305 acres, 63 per cent of which is grazing land. The average head of stock on the grazing land, in terms of cattle, per square mile is 45. The average annual rainfall over these districts varies from 15 to 25 inches, with a mean of close to 20 inches. The average cattle and horse grazing season is about 6 months, and the average sheep season is 3 months. Sheep are converted into cattle with the ratio of 5 to 1.

In the Bighorn National Forest, which covers 1,136,200 acres, 99 per cent of which is grazing land, the average head of stock per square mile, in terms of cattle, is 43. The average annual precipitation is from 18 to 22 inches. The Shoshone National Forest covers 1,609,000 acres, only about 34 per cent of which is grazing land. The annual precipitation is between 15 and 25 inches, and the average cattle per square mile of grazing land is 32. The Medicine Bow Forest of 511,382 acres, 34 per cent of which is grazing land, is credited with 80 head of cattle per square mile of grazing land. The annual precipitation is from 15 to 20 inches. The Washakie Forest, of somewhat smaller area, of which 76 per cent is grazing land, carries 45 head of cattle per section of grazing land. The precipitation is 20 to 25 inches. The Hayden Forest, where the average annual precipitation is 15 to 20 inches, is allowed 58 per section. A considerable number of the sheep in this forest use the Routt National Forest in Colorado part of the season, hence the acreage per head is not so representative as on the other forests. The proportion of sheep to cattle is much greater in this area, also, than on the others mentioned above.

The greater difference in the stock grazed, with nearly the same precipitation, in the different forest reserves in Wyoming illustrates the difficulty in establishing a workable relation between the two factors.

Large areas of land in southwestern Wyoming are grazed by Utah stockmen during the 4 months from January to April, inclusive. It is considered that it will take 2 acres per month per sheep and about 6 times that for horses and cattle. This is at the rate of 13 head of cattle per square mile for the grazing season of 4 months. The rainfall in this region varies from nearly 20 inches close to the Utah border to less than 10 inches toward the edge of the Red Desert.

In all of this northern region some feeding must be done, especially of sheep, when the ground is covered with snow.

On the open range in central Wyoming when the average annual rainfall is from slightly less than 10 to slightly over 15 inches a fair grazing average is 15 acres to the sheep, 40 acres to the cow, and 50 acres to the horse. Averages from a considerable number of reports from different sections of the State give the following grazing values: Where the average annual precipitation is less than 15 inches the average grazing of cattle is 19 to the square mile; where the precipitation is between 15 and 20 inches, 39 head, and where over 20 inches, 52 head.

It is stated that the ranges in Montana will support more stock during the winter than those considerably farther south. One writer states that the local ranges will support a sheep in winter on 5 acres over considerable areas. This will mean from 16 to 20 head of cattle per square mile where the rainfall is from 15 to 20 inches.

A high rolling range on the Lewis and Clark National Forest in Montana supported 1 cow to every 7.37 surface acres, furnishing 2.65 forage acres per cow for a period of 100 days. The annual rainfall in this region is close to 25 inches and the grazing rate is 87 per section for 100 days.

The State of Idaho has a wide difference in the average annual precipitation, from less than 10 inches in the southwest to over 30 inches in the western mountain slopes. The seasonal precipitation is also quite variable; the summer has the least of the four seasons.

Because of this and the further fact that very complete information has been obtained by the section director of the Weather Bureau at Boise, Idaho, the data for the different National Forests in that State will be given a good deal in detail.

Boise National Forest Range: Average annual precipitation, 7 stations, 25.3 inches; elevation of reporting stations, 3,300 to 5,500 feet; carrying capacity per square mile, 16 cattle, 200 to 225 sheep, April 1 to October 15; low range, June 1 to October 15; high range, June 15 to October 15. Range completely stocked with 136,000 sheep and 5,000 cattle.

Caribou National Forest: Precipitation, 3 stations, 14.8 inches; elevation, 5,200 to 6,300 feet; carrying capacity, 20 cattle and 260 sheep. Notes by forest supervisor: "A considerable part of this range is used by sheep and cattle in common. Taking the total forest as a whole and considering all stock handled under permit, each square mile is supporting approximately 20 head of cattle and 260 head of sheep."

Challis National Forest: Annual precipitation, 3 stations, 14.7 inches; elevation of stations, 5,300 to 6,200 feet; season about 6 months; grazing capacity, cattle 12 per square mile; sheep, no data. Note by forest supervisor: "In making an estimate of this kind, large bodies of land must necessarily be included which are incapable of supporting any class of stock. This includes rugged country that is too rough for use by domestic stock as well as large areas of dense timberland which supports absolutely no forage of any value."

Clearwater Forest: Annual precipitation, 1 station, 48.7 inches; elevation, 3,735 feet; carrying capacity, 20 cattle and horses, June 1 to October 31; 200 sheep and goats, June 15 to October 31. Note by forest supervisor: "Owing to timbered conditions this forest is not considered a grazing forest and can never be developed as such. In ordinary range management it is found that horses require about 25 per cent more range space during a given period than is required by cattle, on account of the fact that they are more readily disturbed, travel greater distances and at greater speed. However, they require but little more forage. A band of dry sheep (ewes) will not consume as much forage as a band of ewes with lambs."

Coeur D'Alene Forest: Precipitation, 5 stations, 39.9 inches; elevation of stations, 2,157 to 4,082 feet; carrying capacity, 80 cattle, 6 months; 160 sheep, 4 months. "The National Forests north of the Salmon River are principally important for timber production and not more than 25 per cent of them have any value for grazing.

There is, however, in the aggregate a large acreage of land suitable for sheep grazing and a considerably smaller amount suitable for cattle grazing. The cattle range on the National Forests is found mostly in meadows along the various streams, and the carrying capacity of such areas is comparatively high."

Idaho Forest: Precipitation, 5 stations, 24.6 inches; elevation of stations, 2,200 to 5,025 feet; carrying capacity 19 cattle (season not given), 100 sheep from July 1 to September 30. "A great portion of this forest is very steep and rocky, so that cattle and horses can not use it. There are a few tracts on which cattle and horses graze, and these support about 2,000 head, or 40 head to the square mile. The forest is heavily timbered, at a high altitude, and has many prominent rocks and ledges which tend to make the growth of forage plants less abundant."

Lemhi Forest: Precipitation, 6 stations, 9.7 inches; elevation of stations, 4,040 to 7,150 feet; carrying capacity, 60 to 70 cattle and horses, July 1 to October 31; 375 sheep (counting lambs), July 1 to September 30. "Ranges outside the forest generally have a considerably lower carrying capacity. Stockmen locally usually estimate that a 640-acre homestead will support about 40 or 45 head of cattle and horses. It will support five or six times as many sheep."

Minidoka Forest: Precipitation, 6 stations, 11.0 inches; elevation, 4,550 to 7,600 feet; carrying capacity, 50 cattle and horses, May 1 to October 31; 250 sheep, June to October 31. "Where mixed grazing, that is, both sheep and cattle, there is increased carrying capacity because of the fact that there are certain forage plants more suitable to one class of stock than to others, and where both kinds of stock are grazed on the same area it tends to a more full utilization of the forage crop."

Nezperce Forest: Precipitation, 5 stations, 26.0 inches; elevation, 1,397 to 4,000 feet; carrying capacity, 80 cattle, 6 months; 160 sheep, 4 months. Conditions are similar to those on the Cœur d'Alene range.

Payette Forest: Precipitation, 4 stations, 24.8 inches; elevation, 3,300 to 5,200 feet; carrying capacity, 25 cattle, 6 months; 100 ewes with lambs, 4 months. "There are many factors—altitude, soil, precipitation, exposure, and drainage—which cause a variation of forage plants, their growth and density, even upon limited areas. By far the greater portion of the Payette Forest is timbered brush land, approximately 90 per cent of it being classed as forest. It is all classed as summer grazing land.

Pend Oreille Forest: Precipitation, 3 stations, 28.8 inches; elevation, 1,665 to 2,380 feet; carrying capacity, 64 to 80 cattle, 3 to 4½ months; 100 to 160 sheep, 3 to 4½ months. "Grazing in this forest is in its infancy, although we are just about stocked. Considerable cattle range is on mountain meadows, and in such localities the carrying capacity is somewhat greater than indicated by the figures above, which represent average conditions for the entire range."

St. Joe Forest: Precipitation, 6 stations, 41.0 inches; elevation, 2,155 to 3,735 feet; carrying capacity, 8 to 10 cattle, May 1 to September 30; 125 to 160 sheep, June 1 to September 30. "The above figures are based upon the fact that there are areas within the boundaries of various stock allotments which are unsuited for grazing purposes of any kind. Northern Idaho is not normally a grazing country, and were we to consider the carrying capacity of all mountain and timber lands in northern Idaho the number of acres necessary to support either sheep or cattle would be much greater than the figures shown above."

Salmon Forest: Precipitation, 3 stations, 9.5 inches; elevation, 4,040 to 5,300 feet; carrying capacity, 14 cattle and horses (season not given); 75 sheep for 5 months. "Much of the grazing land in this forest will not carry more than 50 sheep or 9 head of cattle or horses per square mile during a season of 5 months. But we have many small areas that will easily carry 200 head of sheep or 40 head of cattle or horses per square mile for the same season. From the best information available we estimate that the average for the forest is approximately 75 sheep or 14 cattle and horses per square mile."

Sawtooth Forest: Precipitation, 5 stations, 18.8 inches; elevation, 5,347 to 6,200 feet: carrying capacity, 60 cattle, 320 sheep, June 1 to September 30. "On the open forest range 3 acres is necessary to support a sheep and from 8 to 10 acres for a cow. This means the entire range, including waste land and timbered areas containing but little feed. On open country producing a first-class stand of forage probably one and a half acres would be sufficient to support a sheep."

Selway Forest: Precipitation, 2 stations, 31.8 inches; elevation, 1,397 to 4,000 feet; carrying capacity, 60 cattle and horses, 300 sheep and goats, summer range. "Horses and cattle demand a different class of range from sheep and goats, the former preferring a strictly grass range, while sheep prefer weeds, and goats, brush."

Targhee Forest: Precipitation, 5 stations, 21.1 inches; elevation, 5,100 to 6,440 feet; carrying capacity, 60 cattle and horses, 300 sheep, May 1 to October 31. "Capacity varies greatly. Some grazing units will support 125 head of cattle to the square mile for a 6-month period, while there are sections that will not support more than 25 head, due to the fact that considerable land throughout the forest supports but little forage and is classed as waste range."

Weiser Forest: Precipitation, 7 stations, 22.6 inches; elevation, 2,200 to 5,025 feet; carrying capacity, 20 cattle and horses, 80 to 90 sheep. Grazing season, low range (cattle and sheep), March 1 to December 15; high range (sheep), April 1 to November 30. "On the Weiser Forest there is more waste land and land with lower forage value within the sheep range than within the cattle and horse range. This accounts for the low ratio. This is not good range for the dry summer months. From the middle of June to the last of September stock should be on higher green feed."

Averaging all the above forest areas in Idaho with an average annual precipitation less than 15 inches, we find that the carrying capacity is 32 head of cattle and horses and 240 sheep and goats for each square mile.

The forests where the average precipitation is between 15 and 25 inches, the carrying capacity averages 37 cattle and horses and 178 sheep and goats. Where the precipitation is over 25 inches, the forests average 43 cattle and horses and 188 sheep and goats per square mile. In those forests where the average precipitation is between 15 and 25 inches, the summer rainfall is relatively considerably less than during the other seasons as compared with the other areas.

If grouped by the carrying capacity of the forest areas, however, we find that the eight forest ranges grazing an average of 16 head of cattle and horses and 149 sheep and goats have an average annual precipitation of 25.2 inches, while nine areas which graze an average of 61 cattle and horses and 234 sheep and goats receive an average annual precipitation of only 22.8 inches.

Apparently, then, there is little, or no, relation between the grazing capacity of the forest ranges in Idaho and the annual, or even the seasonal precipitation.

In the State of Washington, well-cleared and productive land is too valuable to be used for grazing. In the grazing districts, the carrying capacity varies widely in different localities, depending upon the temperature, rainfall, topography, etc.

On the open range in Benton County in the central-southern part of the State, where the average annual precipitation is only 8 to 12 inches, it is estimated that 10 horses or 14 to 16 cattle per square mile can be carried for the grazing season of 7 months.

On the open range in the Yakima and Wenatchee districts in south-central Washington, where the annual precipitation is from about 11 inches (Yakima district) to about 16 inches (Wenatchee region) it is estimated that a section will carry from 10 to 12 cattle, or 100 sheep during the grazing season of 7 months. On very good range in that vicinity, 125 sheep, or 12 to 15 cattle can be run.

The conditions vary so widely in the different forest reserves and even in different parts of the same reserve in this State, that much depends upon experience and judgment of the men in charge.

In the Colville Forest Reserve, where the annual precipitation averages 17 to 22 inches at the lower altitudes, they calculate 40 acres for one horse, or 30 acres for one head of cattle for the season from May to November, inclusive. This is at the rate of 21 cattle to the square mile. Sheep need about 5 acres per head for 4 months.

In the Wenatchee Forest, where the precipitation is 14 to 18 inches at the lower altitudes, it is estimated that a section fully covered with edible vegetation would graze 200 sheep, or 20 to 25 cattle for the grazing season of 4 months. But as no such extensive areas are found, the stock allowed varies from 5 to 25 acres per sheep and 25 to 70 for 1 head of cattle.

A rough estimate for the Wenaha Forest, where the precipitation is 25 inches, a section will support 112 sheep or 28 cattle, or 22 horses for the grazing season of normally 7 months for cattle and horses and 4 months for sheep.

The Chelan Forest is very rugged, and while there are places where 1 acre would graze a sheep, there is no feed in the larger part of the reserve. A conservative figure for the good range is 10 acres for 1 head of cattle or 7 or 8 sheep. The rainfall for the lower altitudes is 12 to 25 inches.

In the Puget Sound country, where the average annual precipitation is 35 to 45 inches, the best subirrigated cleared bottom land properly cared for will maintain at least 1 cow per acre, thus surpassing the condition in the bluegrass country in Kentucky with an equivalent rainfall.

The seasonal distribution of the rainfall seems to be of more importance in California than the average annual fall in considering the relation to grazing. In one section of the Santa Barbara National Forest in southern California the rainfall in 1918 was about 21 inches, but instead of being well distributed through the winter months it did not come until February. It was not followed by good spring and early summer rains; as a result ranges carried only about one-third as much stock as usual. A little more than one-half as much rain well distributed would have given far better results.

In the Cuyama Valley watershed, on the north side of the coast ranges, the average rainfall is only about 12 inches; but because of summer thunderstorms there is as good grazing as on the south side, where the rainfall averages 18 to 20 inches. To produce the best grazing conditions, precipitation must occur early in the fall and then at intervals through the winter and spring. Late spring rains increase the foothill feed. Heavy winter snowfall in the higher mountains increases the feed in the higher pastures.

Foothill ranges in northern California carry from 32 to 50 head of cattle per section for the winter and spring seasons only. From Fresno south the foothill ranges on the east carry from 32 to 40 head per section for the yearlong season.

In the western portion of the Trinity Forest, where the rainfall is about 60 inches, the better class of grazing lands carry from 25 to 30 head per square mile. On the east side, where the rainfall averages about 42.5 inches, it requires from 40 to 70 acres of grazing land per head, which amounts to some 10 to 16 head per section, including lands of all types. In addition to the heavy rainfall received by the lands on the west they are also subject to fog during the greater part of the year.

In general, in many parts of the State, where the rainfall averages from 12 to 18 inches a year, the supporting value of the range is about 1 beef animal to each 12 to 15 acres of land, or at the rate of from 43 to 53 per square mile.

In central and northern Nevada about 11 head of cattle and 28 sheep are pastured on a square mile of range grasses. The grazing season is from April 1 to November 15. The average annual precipitation for the areas considered is close to 10.5 inches. The average precipitation, mostly in the form of snow, during the three winter months is about 3.50 inches. While much of the water from this snow flows into streams and is used for irrigation, a considerable amount furnishes moisture for grasses at lower elevations during the first part of the summer and at higher elevations during the latter part and in early fall, when the rainfall is usually light.

While cattle and sheep do not feed upon the same areas, a flock of sheep is often pastured on a range not far from a range used for cattle. Frequently one side of a mountain will be used as a sheep range and the other side for cattle. Hence the number indicated per square mile includes both cattle and sheep.

The period covered by stock on the winter ranges in the southern half of Nevada extends from about November 1 to April 15. The annual precipitation on these winter desert ranges is from about 5 to 7 inches, while the stock grazed per square mile averages about 6 head of cattle and 24 head of sheep.

In the tables following an attempt has been made to summarize the data given above into averages. We recognize the fact that these are applicable only in a very general way, but can be used in the absence of more definite experimental and observational data.

RELATION BETWEEN PRECIPITATION AND THE GRAZING CAPACITY OF RANGES.

TABLE 1.—*Arizona, New Mexico, Texas, and Oklahoma, where grazing is mostly all the year.*

Annual precipitation:	Cattle per square mile.
0 to 5 inches	0
5 to 10 inches	9
10 to 15 inches	15
15 to 20 inches	24
20 to 25 inches	32

TABLE 2.—*In the Great Plains States north of Oklahoma, where there are usually periods of considerable length in the wintertime when grazing is not possible.*

Annual precipitation:	Cattle per square mile.
10 to 15 inches	19
15 to 20 inches	38
20 to 25 inches	76
25 to 30 inches	265
30 to 40 inches	409

TABLE 3.—*In the central and upper Rocky Mountain and Pacific States, mostly summer ranges, the period of grazing, varying from 3 to 7 months, depending upon the location.*

Annual precipitation:	Cattle per square mile.
5 to 10 inches	20
10 to 15 inches	28
15 to 20 inches	47
20 to 25 inches	63
25 to 30 inches	97

The greater grazing capacity with the lighter rainfall amounts in the first part of Table 3, as compared with Table 2, is undoubtedly explained by the shorter grazing period in the Rocky Mountain States. On the other hand, the smaller capacity with the heavier rainfalls in the last part of Table 3 as compared with Table 2 seems to be because the regions of heaviest rainfall in the Rocky Mountain States are at the highest elevations where the country is very rough and the available grazing areas small as compared with the Great Plains territory.

The ratio between the number of sheep that can be grazed as compared to cattle as given by different men varied between 14 and 2 to 1. The average is 7 sheep to 1 head of cattle, and this is the ratio that was used in changing the number of sheep grazed into terms of cattle.

In the following table all of the available data from the Great Plains westward are averaged together after correcting for the period of grazing. That is, if the grazing period is only 6 months, the grazing capacity as reported is divided by 2. If it is only 4 months, the capacity figures are divided by 3.

TABLE 4.—*Relation between the annual precipitation and the grazing capacity of ranges from the Great Plains westward (not including California).*

Annual precipitation:	Cattle grazed per square mile.
0 to 5 inches	0
5 to 10 inches	8
10 to 15 inches	14
15 to 20 inches	20
20 to 25 inches	43
25 to 30 inches	66
Over 30 inches	138

While Table 4 may represent the theoretical grazing capacity of ranges for all-the-year grazing, it is not so reliable as the preceding tables, which show averages for the actual grazing that is taking place under different rainfall amounts and for such periods as the season will allow.

The author wishes to give due credit for valuable data furnished by the field officials of the Weather Bureau and the Forest Service.

NEW AEROLOGICAL APPARATUS.[1]

By S. P. FERGUSSON, Meteorologist.

[Weather Bureau, Washington, D. C., July, 1920.]

SYNOPSIS.

The height to which a balloon will rise depends primarily upon the ratio of the lift to the weight carried. The large rubber balloons of either the Assmann or Paturel type required to lift the meteorographs heretofore employed in aerological investigations are costly, and doubtless this circumstance has limited the use of *ballons-sondes*. An investigation of the methods and requirements of aerology has led to the production of a new meteorograph of very simple construction, important parts of which can be made economically in quantity. The scales, particularly that of the pressure-element, are wider than those of other instruments of the kind, the various operations of preparation and reading the records have been simplified, and the weight is less than one-third that of the next lightest instrument that has been used with *ballons-sondes*.

One or two small pilot balloons, costing but one-tenth as much as the Assmann balloons, can lift the new meteorograph, and since the pilot balloons are of better quality the heights attained should be greater than those now possible with the larger balloons and heavy equipment.

An experimental engraving meteorograph and a temperature-element without pivots, suitable for use with the Goddard rocket or in other apparatus are described in order to suggest the direction of further study and experiment.

INTRODUCTORY.

The maximum height attainable by a balloon depends primarily upon the relative density of the gas in the balloon and that of the air, the ratio of the weight to the total lift at the ground, leakage, differences of temperature, and the material of which the balloon is composed. The maximum height, or "ceiling", of a balloon of rigid materials (silk, paper, goldbeater's skin, etc.) may be determined approximately by the degree of inflation required to raise it from the ground. If it will rise when one-half, one-fourth, or one-eighth full, and so on, the maximum height will be where the atmosphere is one-half, one-fourth, or one-eighth, etc., as dense as it is at the ground. Obviously, even if it is made of very light material, such a balloon must be very large if great heights are desired; and during the first campaign with *ballons-sondes*, the French experimenters, considering all circumstances, placed the practical limit of the method at 30,000 meters, if a balloon whose capacity was 5,000 cubic meters were used. Up to 1902 the capacity of the paper and silk balloons used by Teisserenc deBort and Assmann was about 500 cubic meters, the excess lift about 140 kilograms, and the average and maximum heights attained, about 8,000 and 18,000 meters, respectively.

The Assmann expanding balloon, introduced in 1902, revolutionized aerological exploration, for, with a sealed rubber balloon containing but 6 cubic meters of hydrogen, the average height attained has been between 12,000 and 15,000 meters and the maximum 35,000, or almost twice the heights previously accomplished by rigid balloons. The highest ascension in the United States, by Mr. Sherry, then of the Weather Bureau, is particularly noteworthy for the reason that trigonometric observations of altitude were made at two stations up to the highest point reached (32,000 meters).

The most important advance in the direction of economical experimenting has been made by Mr. W. H. Dines, whose baro-thermograph weighs but 48 grams and can be lifted by a small pilot balloon. Time is not recorded by this instrument and progressive changes of condition must be determined from frequent ascensions.

The heights attained by the Assmann balloons have been very variable, chiefly because of the variable

[1] Presented in large part before the American Meteorological Society, Washington, D. C., April 22, 1920.

quality of the sheet rubber of which they are made. The moulded balloons supplied by Paturel and others are much better, but the efforts of Fassig in 1906, and others since that time, to secure balloons of this kind large enough to lift the meteorographs usually employed, have not been successful, probably for the reason that the moulding process is economical only in the production of small balloons in large quantities.

After the completion of the first exploration with *ballons-sondes* in this country, in 1907, the writer made a few tests of Paturel balloons and some experimental devices with the object of developing, if possible, recording apparatus suitable for use with small balloons. These experiments indicated the probability of success by the use of apparatus based upon a special kite-meteorograph, designed in 1905, the weight of which was but two-thirds that of other instruments having the same range and capacity. Opportunity to make use of this new design did not come until 1919, when it was submitted to the committee of the Weather Bureau investigating the Goddard exploring rocket, with the suggestion that the possibilities of *ballons-sondes* had not been exhausted.

The first instruments of this new pattern were received in December, 1919. As yet, no ascensions have been attempted, but tests in the laboratory indicate that requirements have been met very satisfactorily.

Comparison of balloons and meteorographs.

ASSMANN BALLOONS.

	No. 1.	No. 3.	No. 5.
Diameter:			
Full	1.20 meters	1.50 meters	2.00 meters.
Distended	1.35 meters	1.75 meters	2.25 meters.
Weight	1.36 kilograms	1.50 kilograms	3.23 kilograms.
Capacity:			
Full	1.00 cubic meter	2.00 cubic meters	4.00 cubic meters.
Distended	1.50 cubic meters	3.00 cubic meters	6.00 cubic meters.
Lift:			
When full	1.00 kilogram	2.00 kilograms	4.00 kilograms.
When distended	1.50 kilograms	3.00 kilograms	6.00 kilograms.
Cost (1910)	$12.00	$17.00	$36.00.

BALLOONS OF THE PATUREL TYPE.

Diameter.	Weight.	Diameter at time of rupture.	Lift, when half inflated.	Lift, inflated to point of rupture.	Cost.
	grams	*mm.*	*grams*	*grams*	
165 millimeters *	28	930	200	400	$0.75 (1918).
200 millimeters †	34	1,200	600	1,200	1.80 (1908).
220 millimeters *	36	1,100	400	800	1.50 (1918).
300 millimeters *	43	1,500	1,000	2,000	2.00 (1918).

* Made in the United States, 1918.
† Made by Paturel, Paris, France, 1908.

METEOROGRAPHS AND ACCESSORIES.

Meteorograph.	Weight of—			Total weight.	Hydrogen required.	Cost, instrument only.	Cost of accessories.
	Instrument.	Parachute.	Basket.				
	grams	*grams*	*grams*	*grams*	m^3		
Bosch (Germany, 1904)	600	500	500	1,700	2.5	$100.00 *	$10.00 *
deBort (France, 1904)	400	425	113	938	1.5	55.00 *	7.50 *
Fergusson (U. S. A., 1919)	180	50	45	275	1.0	100.00 †	3.50 †

* In Europe, 1904-1910.
† In America, 1919.

The quantity of hydrogen stated is that necessary to give an excess or surplus lift of 500 to 1,000 grams. When the Bosch instrument is employed this excess is obtained only when the largest Assmann balloons are used. For the deBort meteorograph, the No. 3 Assmann balloon usually is sufficient and very probably two 300-millimeter Paturel balloons would be satisfactory, although possibly the rate of ascension would be slower than with a larger balloon. The important result shown by these comparisons is that aerological exploration with small, light apparatus is far less costly than when heavy instruments of older patterns are employed; also, if the market values of the instruments are corrected to the same year it will be seen that the new instrument is the least costly of the three.

DESCRIPTION OF THE NEW METEOROGRAPH.

Practically all meteorographs that have been used with *ballons-sondes* are simple modifications of well-known baro-thermo-hygrographs. Experience, and the analysis already referred to, of the methods of aerology, indicated a need of improvement in the following particulars:

(1) Instruments generallly used are unnecessarily complex, most parts are handmade and not adapted to production in quantity, and repairs ordinarily can not be made except by a skilled instrument maker.

(2) Rigidity, or resistance to flexure, of supports, usually secured by the use of thick base plates and braces attached to pivot supports, is not permanent.

(3) The ordinary commercial clocks used run 30 to 40 hours with one winding. The time-drum rotates once in one hour, and since an ascension seldom occupies more than three hours, portions of the record are frequently obscured or lost because of tracings of surface conditions superimposed after the instrument reaches ground and before the clock stops. Several devices have been employed to remove the markers from contact with the record sheet or stop the clock, etc., but all these add to the cost of the instrument and increase the number of operations to be performed at the time of an ascension. Instances have occurred of loss of records due to failure to set such devices.

(4) The number of operations required when the instrument is prepared for an ascension and in measuring and reading the records is unnecessarily large.

It is believed that in the design of the new meteorograph these defects have been avoided, although further improvement, particularly in rendering the mechanisms more easily accessible is to be desired. The most important deviations from prevailing usage are (1) the use of simple parts that can be produced economically, (2) the use of a system of construction whereby strains tending to cause flexure and disturbance of adjustment are supported by the edges and cylindrical parts of the case and base, (3) the adoption of a single time-arc for all markers, and (4) the use of a two-part scale for the barograph.

The general appearance of the meteorograph and the basket is shown by the two photographs. The cage or basket is composed of three hoops of rattan provided with two crosspieces on which the instrument rests. Light cords attached to metal loops on the case serve to keep the instrument in the center of the cage, where it is easily accessible for adjustment at any time before an ascension. Details of the case, supports, clock, etc., are shown in figures 1 to 12, inclusive, and a schematic record appears in figure 13.

Clock.—The clock, usually the heaviest single part of a light recording instrument, received attention first. The movement employed, which was selected from a number of the simpler American clocks, is of the same general

character as the well-known Ingersoll watch, but is stronger and the teeth of the pinions are cut. The quality is, perhaps, more variable than is desirable, but the movement is a good timekeeper and so cheap that it is economical to use even if the number of rejections is large.

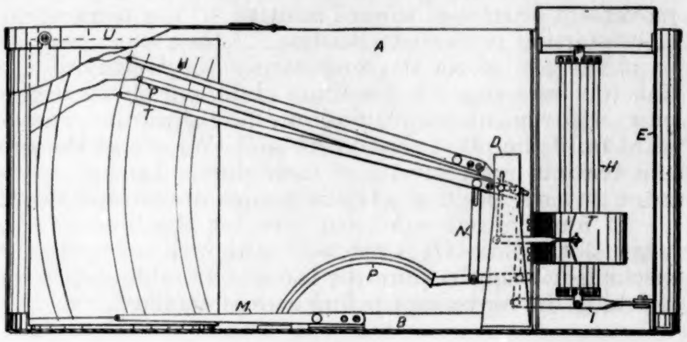


FIG. 1

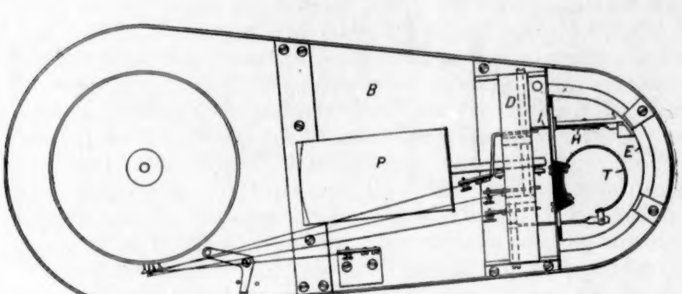


FIG. 2

It has been found satisfactory in kite meteorographs. As shown in figures 3 and 4, the heavy spring and gear usually employed to drive the clock for 30 hours, together with adjacent portions of the plates (indicated by dotted lines), have been removed and a mainspring (S) placed directly on the center staff or minute-hand arbor, to which the time-drum is clamped. At this point a small watch spring is amply powerful and the number of rotations of the drum (ordinarily less than seven) can be limited as desired by winding the spring the required number of turns.

The cylindrical part of the time-drum is of hard sheet aluminium about No. 35 gauge, fitted to heads spun from heavier metal (No. 26 gauge). Cylinders made in this way are much lighter than those cut from tubing and a true cylinder is more easily obtained. The lock seam (C) projects inside, hence does not obstruct the markers. The drum is clamped to the top of the center staff and the bottom flange or head fits smoothly over the adjustable collar (F), just above the clock case (fig. 4). This method of securing the drum admits of unclamping and adjusting for time without disturbing other adjustments; also, the left-hand thread on the center staff admits of winding the mainspring simply by turning the drum backward, after the clamp screw is tight.

Recording mechanisms.—These are of the same general character as similar parts of instruments devised by Richard, Bosch, and others, but much lighter. The Bosch method of adjusting the ranges of the elements is employed.

Temperature-element.—This is a strip of "thermostatic metal," composed of closely-united sheets of invar and bronze, but 0.2 mm. thick, and, with the possible exception of Richard's temperature-element, far more sensitive and more powerful than any formerly employed in instruments of this kind. The exposure of the temperature-element is shown in figures 1 and 2. The element (T) is secured inside the tube (E) which extends vertically through the case of the meteorograph but is attached only to the base-plate and the upright carrying the recording mechanisms. (T) is insulated from (E) and from the upright so that there is no conduction of heat from the base or cylinder, also, since air can pass freely between the cylinder (E) and the case, the element is not affected by radiation from any part exposed to direct sunshine. The range adopted is 1 mm. to each 2° C.

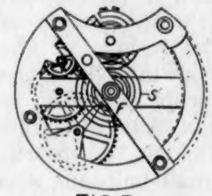


FIG. 3

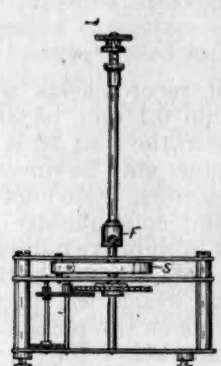


FIG. 4

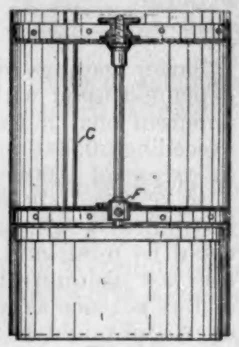


FIG. 5

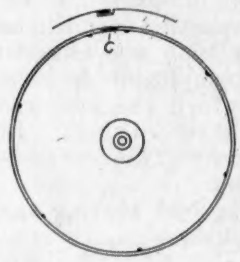


FIG. 6

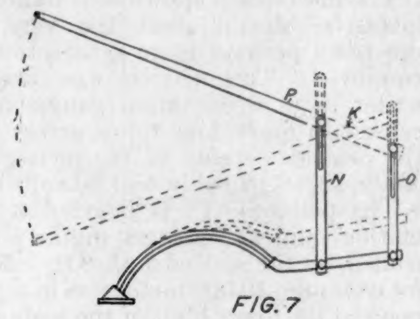


FIG. 7

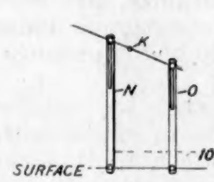


FIG. 8

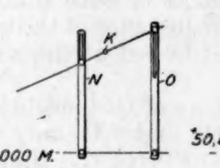


FIG. 9

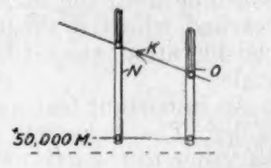


FIG. 10

Pressure-element.—When, as in the present instance, the records may extend practically through the entire range of atmospheric pressure, a wide scale is desirable in order that the very small changes at great heights may be recorded and read with reasonable accuracy. An ordinary or usual ratio of the scale of a recording instrument to that of the mercurial barometer is about 1 to 10, i. e., 1 mm. of movement of the pen of a barograph at sea level is equal to a change of pressure of 10 mm. of mercury. As shown in the accompanying table, this scale, at great heights, becomes so contracted that a considerable change of height causes so small a movement of the recording pen that the determination of the height or other circumstances of an important change of condition becomes very uncertain.

Values of the pressure-scale at different heights.

Height.	Pressure.	Difference or change.	Scale of Meteorograph.	
			One-part, (1-10).	Two-part.
	mb.	*mb.*	*mm.*	*mm.*
Sealevel	1,013.3			1-10 {....
5 kilometers	540.0	473.3	35.5	35.5
10 kilometers	224.0	316.0	23.7	23.7
15 kilometers	119.9	104.1	7.7	1-5 {15.4
20 kilometers	54.7	65.2	4.8	9.6
30 kilometers	11.5	43.2	3.2	6.4
40 kilometers	2.2	9.3	0.7	1.4
50 kilometers	0.5	1.7	0.1	0.2

Since readings of record-sheets usually can not be depended upon within 0.1 mm. of space traversed, it is apparent that if the ratio 1 to 10 is employed, heights exceeding 30,000 meters may be uncertain to an amount in excess of 2,000 meters. Obviously, with a scale of 1 to 5, the bulk and consequently the weight of the instrument would be prohibitive unless very large balloons could be used; and with the two-part scale indicated in the last column (in which the portion above 10,000 meters is twice as wide as the portion below) the instrument still might be too heavy for the small balloons it is intended to use.

The mechanism shown schematically in figures 7 to 12, inclusive, should meet the very exacting conditions described perhaps more satisfactorily than any hitherto employed. This device was first employed by the writer in a precipitation gauge in which the pen was caused to move four times across the record-sheet. In the present instance of the meteorograph two traverses of the sheet probably will be sufficient.

The pen-arm (P) is heavier at the end bearing the marker, and at sea-level (figure 8), its position is controlled by the slotted link (O). At any desired height, for example, 10,000 meters, as in figure 9, the marker has reached the lower limit of the scale and is prevented from going further in this direction by the other slotted link, (N). If further reduction of pressure occurs, the arm is raised by the link (N), the screw-pin on the other side of the axis sliding downward in the slotted end of the link (O). The movement in this reverse direction can continue until the limits of both slotted links have been reached, which, in the instance of the meteorograph under consideration, should be set at the zero of the pressure-scale.

An important feature of this mechanism is the variable scale. The links (O) and (N) may be so placed with reference to the axis or pivot (K) that the upward movement of the marker has twice the value of the lower (or downward), in order that the small changes of pressure at heights above 10,000 meters may be read with greater accuracy than would be possible with a uniform scale. With a sufficiently powerful pressure-element the upper portion of the record easily could be given three or more times the value of the lower for the same change of pressure.

Mechanism for four-part record.—The mechanism employed to obtain four traverses of the record-sheet, while perhaps more useful in precipitation gauges or other totalizing instruments, may be of some value in aerological apparatus. As shown in figures 11 and 12, both ends of the links (N) and (O) are slotted and the end of the pen-arm to the right of the axis is heavier than the end carrying the pen. Assuming that the device is applied to a weighing gauge whose receiver is displaced downward as rain or snow falls, this movement may be indicated by successive positions (1), (2), (3), and (4) of the bar (G). When position (1) is reached, the pivot screw (Y) is at the top of its slot, and if further movement occurs must carry the weight of the link (N). The pen end of the recording style is now the heavier, and as movement progresses toward position (2) the pen returns to its starting point. At position (2) the pivot screw (Z) is at the top of its slot and carries the weight of the link (O), restoring the condition obtaining at the beginning. Movement toward position (3) carries the pen upward until the pivot screws (Y) and (W) are at the top and bottom, respectively, of their slots. During movement toward position (4) the pen is drawn downward on its fourth excursion until zero (or the limit of the lower slot in link (O) is reached), although safety to the mechanism might require the use of a suitable device for checking the movement before zero is attained.

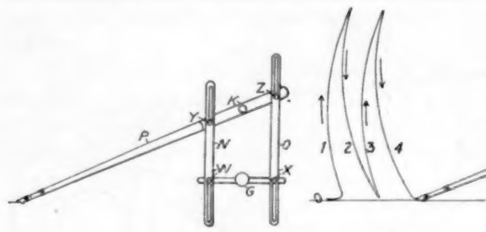


FIG. 11

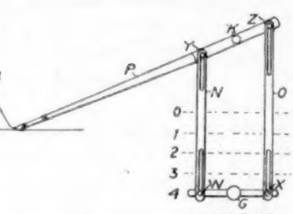
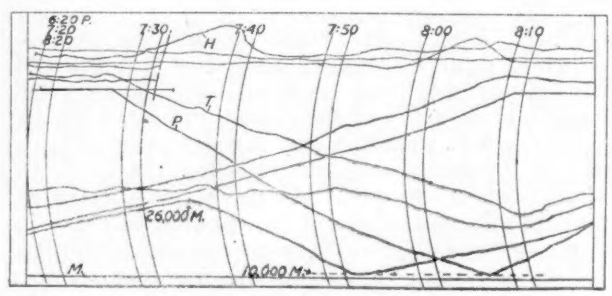


FIG. 12



S.P.F., 1920

FIG. 13

By the use of this mechanism it is possible to quadruple the capacity or the scale values of recording gauges, etc., without costly increase of dimensions of clock-drums, record sheets, etc., or in the instance of seasonal or long-period apparatus to facilitate obtaining records at isolated stations where observers can not be secured.

Humidity.—The humidity-element (H), figures 1 and 2, consists of six or eight strands, each composed of three fine hairs. Tension is maintained by a flat spring (I), the outer end of which is connected with the recording style. By this method of construction the highest degree of sensitiveness is attained and the hairs are protected against direct sunlight.

Support for recording styles.—The pivots of the recording styles are supported by a one-piece aluminium casting (D). All three axes are at the same height and there is but one time-arc for all. The positions of the pivots, screws, etc., are indicated on the pattern, and if smooth castings are obtained the only machining necessary is boring for pivots and screws and smoothing the under side which rests on the base plate. To provide for the double traverse of the pressure-marker, its pivot is placed exactly 3 mm. (or one minute of time) behind the others,

and the recording points are of different lengths so that one may pass over or under the others.

Case and base.—The case (A) is of hard sheet aluminium, 35 gauge (or 0.2 mm.) thick, the cover is secured by a lock seam instead of rivets, and the sides are stiffened by two or more deep "beads" or ribs. The bottom edge is double and is secured to the base (B) by means of machine screws at intervals of about 5 cm. Access to the mechanisms is afforded by a sliding door (shown in the photograph), and the clock-drum is removed or replaced through an opening in the top of the case, which at other times is closed by the cap (U), figure 1. This cap and the sliding door can be secured by screws, so that the instrument is not likely to be opened and injured by a curious finder.

The base (B) is of hard sheet aluminium, 26 gauge (0.5 mm.) thick, and as shown in figure 2, is made as rigid as possible by bending up the edge continuously on all sides.

Considered separately, the case and base are fragile and not so rigid as similar parts of other instruments; but, when put together, they resist, as a solid block, all ordinary stresses, and since as stated, the recording mechanisms are carried in a separate, rigid casting, accidents serious enough to deform both case and base in most instances do not injure these more delicate parts.

Parachute.—For this apparatus, whose weight, including accessories, is but one-third that of the equipment employed by Teisserenc de Bort (the next lightest), a parachute having one-third the surface of the one used by de Bort will be sufficient. The parachute may be dispensed with, but in this event, two pieces of bright-colored silk should be attached to the apparatus to retard the descent and to attract the attention of a possible finder. If a parachute is employed the gores should be of different bright colors to facilitate discovery. Methods of making parachutes are well known and do not require description here.

Record sheets.—These are made of hard sheet aluminium about 44 gauge (0.03 mm.) thick (almost as thin as foil), and can best be secured to the record drum by means of the lockjoint used in the first experiments at St. Louis.

Records.—In figure 13 is shown schematically the kind of record made by the new instrument. The traces may be read by means of a transparent scale, but, as indicated, it will probably be best to rule a pair of time-arcs for each interval of 10 minutes and measure all intermediate readings from these lines. The usual fixed marker, (M), traces a base-line from which the positions of the other markers at different temperatures, pressures, and humidities can be determined, and which serves to detect irregularities in the movement of the clock-drum.

Dimensions and weight.—The external length of the instrument is 210 mm., the height 90 mm., and the greatest width 85 mm. The clock-drum is 80 mm. in length, 57 mm. in diameter, and the time-scale is 3 mm. a minute. The weight of the clock and drum, including a cover for the clock is 65 grams.

METEOROLOGICAL APPARATUS FOR USE WITH THE GODDARD ROCKET.

The Goddard exploring rocket has been suggested as a means for obtaining meteorological data at heights greatly exceeding those accessible by balloons. Propelled by charges of explosive fired at frequent intervals, its velocity is very high, and the ascent to and the descent from a height of 100 kilometers requires only about 10 minutes. Under such circumstances the best methods of measurement now available are not likely to yield data of more than approximate value at first. The vacuum existing above 50 kilometers is not easily attained or measured by an ordinary air pump, and it may be necessary to employ several independent methods to ascertain the conditions at any desired point during either ascent or descent; for, during the descent, a parachute will be of little use until the troposphere is reached. The following methods have been suggested for obtaining heights:

(1) In the daytime, trigonometric measures of smoke-clouds produced at definite intervals by chemicals placed among the charges of explosive. At night charges of magnesium are to be substituted for the smoke-producing materials. (Humphreys.)

(2) The measurement of vacua in a series of exhausted vessels arranged to be opened and resealed at predetermined points. (Humphreys.)

(3) The use of recording apparatus.

The first method is probably the most accurate and the third the simplest, if the scales can be made wide enough to indicate the very small changes occurring in the stratosphere. The development of recording apparatus adapted to these conditions is well worth while, for

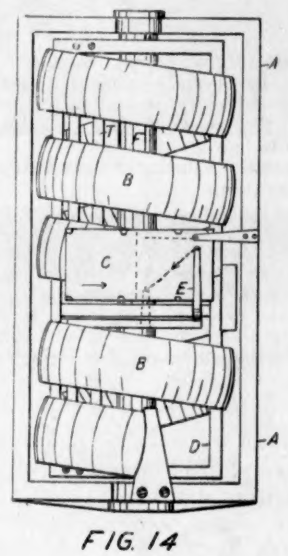


FIG. 14

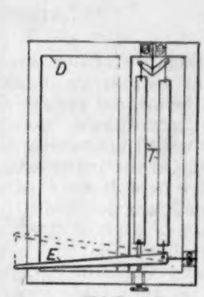


FIG. 15

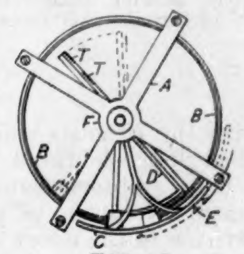


FIG 16

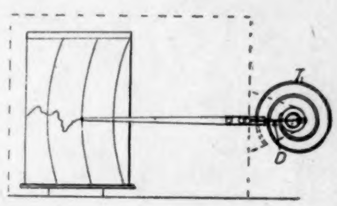


FIG 17

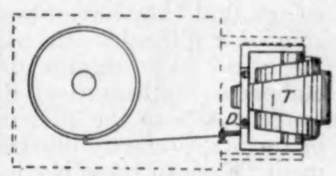


FIG. 18

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there are projects other than the present one of the exploring rocket in which a simple instrument without clock will be useful. The conditions under which such an instrument must function are very trying. The shock of the frequent explosions and the strain caused by the high velocity are very likely to destroy an instrument with delicate mobiles, consequently time-clocks and mechanisms ordinarily employed in measuring temperature and

pressure need not be considered at present. The range of movement required and freedom from vibration must be secured by the use of strong elements well supported.

The apparatus described herein is suggested as a basis for further experimental study. It has not been constructed, but the principle of Mr. Dines's successful engraving instrument has been followed, and essential parts already have been used to a limited extent in instruments produced by Richard and other manufacturers. Referring to figures 14, 15 and 16, the pressure-element (B) is composed of two helical Bourdon tubes secured in a light frame (A), so that their free ends move in opposite directions when there is a change of pressure. A single tube could be used, but the double-tube element is preferred for the reason that thereby may be secured greater compactness and rigidity. One tube carries the record-plate (C), and the other the temperature-element. The latter consists of two or more strips of very thin bronze (T, T), connected by spring hinges and mounted in a light invar frame (D), in such manner that changes of length corresponding to changes of temperature are engraved upon the record-plate by the style (E). The strips (T, T) are insulated from their support.

The inner ends or edges of the plate-carrier (C) and the frame (D), are secured, under tension, to spring hinges in the center of the tube (F), and therefore restrict the motions of the pressure tubes to an arc whose axis is the center of the tube (F). By this means longitudinal movements of the pressure tubes are prevented and there are no pivots with the variable friction inevitable when Bourdon tubes of this kind are mounted in the usual way. Another application of this device, in the construction of a simple thermograph without pivots, is shown in figures 17 and 18. Here, circular motion about the center of the coiled element (T), is obtained by securing to its free end the frame (D). Adjustment for range is accomplished by changing the position of (D) as shown by the dotted lines.

A GENERAL THEORY OF HALOS.

By CHARLES S. HASTINGS.

[Yale University, May, 1920.]

SYNOPSIS.

The general theory of halos developed in this paper rests on the assumptions that two kinds of simple ice-crystals—elongated hexagonal rods and hexagonal plates—are occasionally present in a tolerably transparent atmosphere; moreover, that these crystals subsiding in quiescent air would necessarily fall into four groups.

The first portion of the paper establishes the validity of the assumptions by reference to well-recorded observations.

The second portion is devoted to a development of the consequences from the presence of each of these groups for various altitudes of the sun. It is there shown that all the authenticated features of complex halos are naturally explained (excepting certain rare multiple concentric circles) as inevitable consequences of the hypotheses. In addition, this portion gives a new means of classifying the various phenomena, showing unsuspected relationships as well as essential diversity in certain other cases where common origin was formerly assured.

I.

During the 72 years which have elapsed since Bravais published his celebrated and comprehensive work on halos many observations have been accumulated—some even by means of photography—and much has been written in the effort to improve questionable points in the theory presented by that admirable writer. As regards the efforts of the theorists it does not seem unfair to say that they have been quite futile; at least, no solution of a difficulty left by Bravais, as far as known to me, has ever commanded general acceptance. The elaborate mathematical discussions by Pernter of the tangent arcs to the 46° circle and of the, so called, arcs of Lowitz, perfectly illustrate the rather sweeping statement: Each of these is a logical conclusion from premises which no instructed meteorologist can possibly accept.

Before advancing any new views regarding the highly complex phenomena involved it will be well to summarize what was known when Bravais finished his work. The number of features which he considered and attempted to account for was about twenty. Of them we may ignore one or two as not being sufficiently authenticated, but we must add two which are of unquestionable authenticity; thus the total number remains nearly the same. Unfortunately, a small minority only of these were satisfactorily explained. We may catalogue these here and escape an undue lengthening of this paper by unnecessary repetition.

(1) The ordinary circle about the sun of 22° radius, attributed by Mariotte to the action of ice crystals suspended in the air and having faces inclined at 60°, the directions of their crystallographic axes being entirely fortuitous. This explanation of the commonest of all halos is thoroughly satisfactory and universally accepted.

(2) The 22°-parhelia, often called sun-dogs, are prismatic images of the sun right and left of it and at the same altitude. With a low sun they are at the angular distance named, but at a higher altitude the angular separation increases. They are not seen higher than 50°. At high latitudes they are more frequently noted than any other feature and the explanation—also first advanced by Mariotte—as due to hexagonal ice crystals with persistently vertical axes leaves nothing to be desired.

(3) The parhelic circle—a faint, colorless circle everywhere equally distant from the zenith and passing through the sun. This was attributed by Thomas Young to reflection from the faces of hexagonal prisms falling vertically. Bravais improved this theory by the remark that crystals with their principal axes persistently horizontal would also contribute to this feature. I shall show that probably only such reflection as is total, hence from the interior of the crystals, is generally effective.

(4) Upper and lower tangent arcs to the 22°-circle These are due to the presence of crystals whose principal axes are horizontal, the lateral faces having any direction in space. As the sun rises to an altitude of about 45° these two arcs unite and form a ring inclosing the 22°-halo and touching it at its highest and lowest points. At very high sun this ring, called the circumscribed halo by Bravais, approaches more and more a true circle. This ring may exist alone. Admirable photographs taken at New Haven, Conn., and at Chester, Pa., of the halo of March 20, 1915, have been published in the MONTHLY WEATHER REVIEW.[1] Bravais gave a very complete analysis of these features with tables which may be used to find the position of any desired point

[1] May, 1915, 43: 213-216 and October, 1915, 43: 498-499.

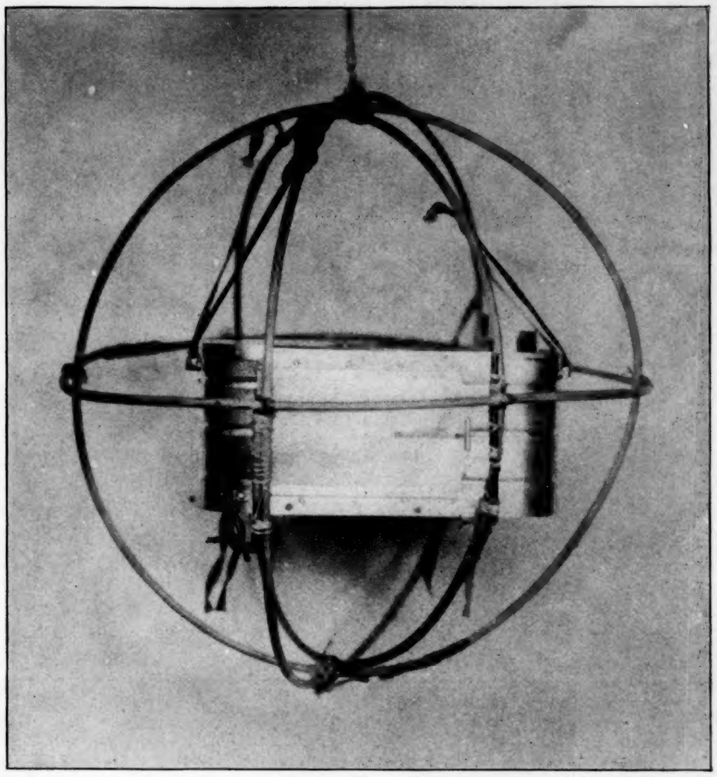

FIG. 19.—Meteorograph in basket.

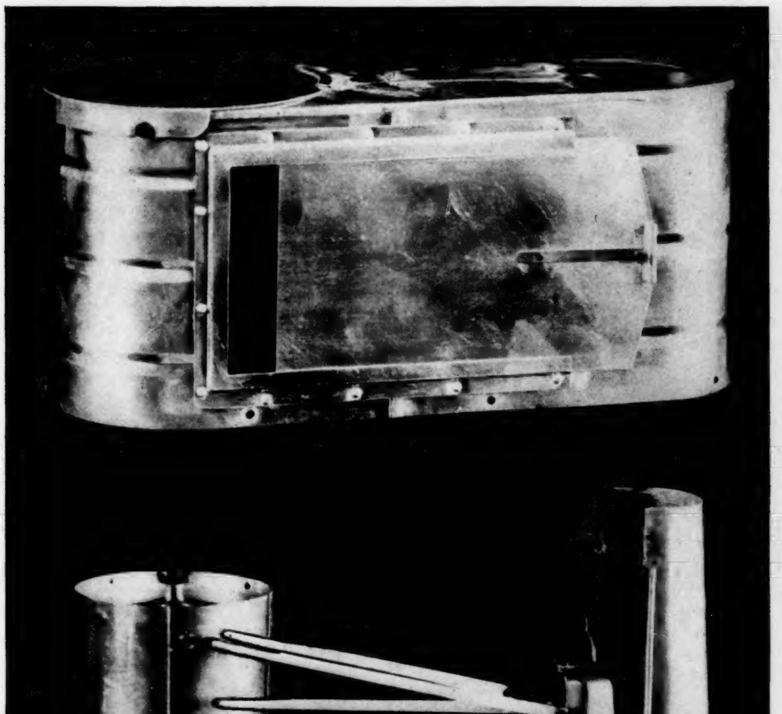

FIG. 20.—Meteorograph with cover removed, showing mechanisms.

Photo by Paul Schultz.

THE SUN DOGS.

FIG. 7.—A reproduction of the remarkable photograph by Paul Schultz in Archdeacon Stuck's book "Ten Thousand Miles with a Dog Sled," page 388, Scribner's, 1914.

with any assigned altitude of the sun. In the calculations which are at the basis of the solutions given below I have saved myself unnecessary labor by recourse to these tables.

(5) Upper and lower tangent arcs to the 46°-halo. These are exactly tangent only in the cases of a solar altitude of 22.1° for the former and 67.9° for the latter, but they may be conspicuous when the sun departs several degrees from these stations. Their forms will appear in certain of the solutions given in this paper. The theory and analysis of this feature by Bravais appears to be faultless.

All theorists since the time of Bravais would doubtless include as a sixth feature of complex halos finally and completely accounted for by him the 46°-halo.

This feature was explained by Cavendish as similar in origin to that of the 22°-halo except that it is produced by prisms having faces at angles of 90° instead of 60°, such as would be formed by a base and any side of a simple hexagonal prism. These refracting edges are assumed to have purely fortuitous directions in space and, as in the case of the 60° prisms, only those which happen to be near the position of minimum deviation are effective. This explanation has been universally accepted and it certainly is recommended by its simplicity; it presents, however, difficulties which are not easily to be disposed of. If it were true, one would expect to see the 46°-circle almost as frequently as the 22°, at least when the latter is brilliant; but this is far from being the case. Again, this accepted explanation would make the appearance as likely with the sun high in the heavens as when the sun is low, which is also very far from true. There is no record of the 46°-circle having attained the zenith or even come very near it—in short, one might assert with considerable confidence that this feature does not appear with the sun more than 32° above the horizon. Again, were this explanation correct, the circle in its ordinary exhibitions ought to appear uniformly bright, as does the 22°-circle. Such a condition may indeed occur, but not according to my rather limited experience. In every case which I have observed the brightness has been far from uniform, but has—a very significant fact—been distributed in arcs symmetrically placed as regards the vertical through the sun. We shall see in Parry's famous record an exactly similar condition. In view of these facts I prefer an explanation offered below which, however, does not exclude the possibility that fortuitously directed crystals play a part in some cases unlike those which have come under my observation.

It will not be profitable to dilate upon the reasons why the explanations of other features of complex halos are held by me as untenable. The only reason of moment is, of course, the belief that the explanations offered here are better, and any reader can easily resolve any doubt as to that by recourse to easily accessible works; I shall, however, permit myself to call attention to those cases where an unforced explanation of a feature as derived in this paper stands without any alternative.

The method adopted by all investigators has been to establish the existence of a feature by reference to the records and then to invent a form of ice crystal which was though adequate to produce it. These inventions are very numerous and some of them of admirable ingenuity. There are two serious objections to such procedure. One is perfectly obvious, namely, the objection to assuming at any particular time the presence of rare, or even unrecognized crystal forms, in such overwhelming numbers as to be effective. The other is a little less evident although even more formidable; the presence of any crystal not immediately effective in the production of a given feature obscures it. The conditions of development of rainbows and of halos are, in a sense, antithetic. In the former the more opaque the background, provided that the opacity is due to raindrops alone, the more brilliant the phenomena; in the latter a considerable transparency of the sky is a primary requisite. Thus economy in the number of types of crystals assumed in any theory is of the highest importance.

In the theory presented here only two form of crystals are postulated both of which are the simplest types of ice crystals and both of which are familiar to observers. The first is that of a hexagonal prism with a short principal axis—in short, a hexagonal plate of which the thickness is a small fraction of its diameter. Such crystals I shall style the A type. The other form is that of a hexagonal prism of which the length is much greater than the diameter; it might be described as a hexagonal rod. This second form I shall designate as the B type. Both types have dihedral edges of 90° and of 120°, the former being the angle at which the basal and side faces meet and the latter that of the lateral faces; but optically (as regards transmitted light) they yield only prisms of 90° and of 60°, the prism of smaller angle being truncated by the plane which forms the intermediate face of the hexagonal crystal.

Such small bodies falling through a quiescent resisting medium would have a decided tendency to assume positions such as to offer a maximum resistance to the relative motion, hence the A crystals would tend to remain horizontal—that is, with their short principal axes vertical—while the B crystals would maintain their principal axes horizontal. This assumption is exactly opposite to that of Bravais and his followers who supposed that such bodies would set themselves so as to meet with the minimum resistance. These assumptions constitute the fundamental difference between the old theories and the present one and should therefore be carefully noted by the critical reader. It is difficult to understand how the earlier view could be taken, notwithstanding the lack of a knowledge of the mechanical principles involved which we now possess, for every one knew of the difficulties met in keeping an elongated projectile in end-on flight.

This tendency to stability of direction of the principal crystalline axis of the two types is far from being a strong one; its effect is as remote as possible from producing a pendulum-like oscillation such as Pernter has assumed as the basis of certain of his explanations. In the latter kind of motion the moment of restitution increases proportionally with the displacement from the position of equilibrium, while in this case of fluid constraint the moment of restitution decreases with departure from equilibrium and wholly vanishes at some indeterminate angle. Thus, although we may have recurrent motion, simulating harmonic motion, in cases restricted to very small amplitudes, the usual result would be a continuous rotation about some major axis. Examples of such motion are familiar to every observer, e. g., as shown by the fall of petals of fruit blossoms, by that of small bits of paper.

With this enlarged view as to the phenomena presented by small, regularly formed bodies in falling through quiescent air, we find that we have, with two

types of ice crystals only, four different groups. These may be designated and defined as follows:

A group; those hexagonal plates which fall with their principal crystaline axis continuously vertical.

A′ group; similar plates which, in falling, rotate continuously about a major diagonal.

B group; those elongated hexagonal crystals which fall not only with their principal axes continuously horizontal but also their maximum cross-section horizontal.

B′ group; crystals like the last but rotating continuously about their principal crystaline axis. Some, or even many, of these may be assumed to have a motion about their centers of mass so that these axes describe cones in space, always, however, of small angular opening.

With these simple postulates the problem of halos divides into two parts, first, to demonstrate from the records the occasional existence of these four groups of crystals in our atmosphere; and, second, to deduce all of the optical consequences from the presence of such crystals and compare these consequences with recorded observations.

There exists one record (only one, unfortunately) which admirably meets our requirements for the first step; it is the halo figured and described in Parry's First Voyage,[2] p. 164–165. This record is peculiar in several respects; first, it was observed in common by two skilled observers, Parry and Sabine, and had a complexity involving three of the groups of crystals named above; and, second, because of the remarkable duration of slowly changing phases due to the high latitude, which was 74° north.

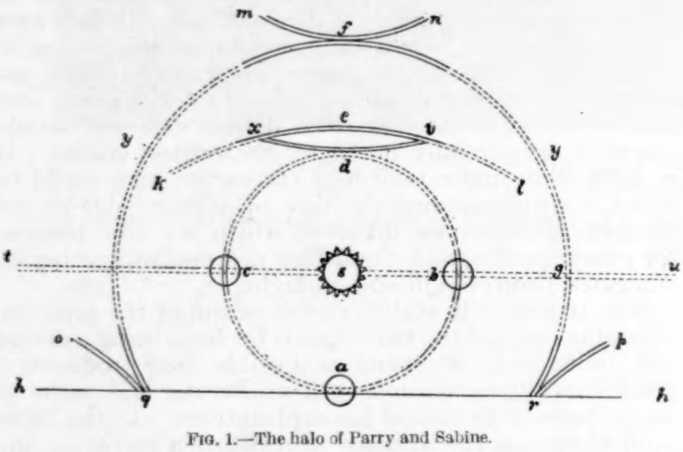

FIG. 1.—The halo of Parry and Sabine.

The diagram and description as given by Parry and Sabine are as follows:

From half-past six till eight A. M., on the 9th, a halo, with parhelia, was observed about the sun, similar in every respect to those described on the 5th. At one P. M. these phenomena re-appeared, together with several others of the same nature, which, with Captain Sabine's assistance, I have endeavoured to delineate in the annexed figure.

s, the sun, its altitude being about 23°, h, h, the horizon.

t, u, a complete horizontal circle of white light passing through the sun.

a, a very bright and dazzling parhelion, not prismatic.

b, c, prismatic parhelia at the intersection of a circle a, b, d, c, whose radius was 22½° with the horizontal circle t, u.

x, d, v, an arch of an inverted circle, having its centre apparently about the zenith. This arch was very strongly tinted with the prismatic colours.

k, e, l, an arch apparently elliptical rather than circular, e being distant from the sun 26°; the part included between x and v was prismatic, the rest white. The space included between the two prismatic arches, x e v d was made extremely brilliant by the reflection of the sun's rays, from innumerable minute spiculae of snow floating in the atmosphere.

q f r, a circle having a radius from the sun, of 45°, strongly prismatic about the points f q r, and faintly so all round.

m n, a small arch of an inverted circle, strongly prismatic, and having its centre apparently in the zenith.

r p, q o, arches of large circles, very strongly prismatic, which could only be traced to p and o; but on that part of the horizontal circle t u, which was directly opposite to the sun, there appeared a confused white light, which had occasionally the appearance of being caused by the intersection of large arches coinciding with a prolongation of r p, and q o.

The above phenomenon continued during the greater part of the afternoon; but at six P. M., the distance between d and e increased considerably, and what before appeared an arch, x, d, v, now assumed the appearance given in fig. 12, plate 287, of Brewster's Encyclopaedia, resembling horns, and so described in the article "Halo," of that work. At 90° from the sun, on each side of it, and at an altitude of 30° to 50°, there now appeared also a very faint arch of white light, which sometimes seemed to form a part of the circles q o, r p; and sometimes we thought they turned the opposite way. In the outer large circle, we now observed two opposite and corresponding spots y, y, more strongly prismatic than the rest, and the inverted arch m, f, n, was now much longer than before, and resembled a beautiful rainbow.

This sketch is not drawn according to any geometric projection and does not admit of quantitative analysis; but if we accept the position angles as referred to the sun and the angular distances as proportionel to the linear distances, we shall be able to redraw it according to any system of projection preferred, since the scale is given by the known angular dimensions of the inner circle. The projection which I shall choose for all of the diagrams in this paper is that known as the spherical projection. Moreover, with a single exception, I shall choose the plane of the paper as that of the horizon, the center of the circle representing the visible horizon being the projection of the zenith. The advantages of this particular system are many; every circle in the heavens is represented by a circle on the plane (which becomes a straight line when a great circle passing through the zenith) and the angle of all intersections is preserved unaltered. Moreover, the coordinates of every point as represented by azimuth and zenith distances are readily found, the first by direct reading from horizon circle and the second by means of a simple trigonometric formula or by a scale constructed for that purpose. The only serious fault is that of a considerable distortion in the neighborhood of the horizon.

Figure 2 represents the observations of Parry and Sabine thus reduced to a spherical projection. I shall proceed to construct a halo, according to the same laws of projection, which would result as a consequence of the fundamental assumptions above. A comparison of the two may be expected to validate these assumptions or the contrary. To do this it is necessary to define certain constants and symbols.

The acented mean index of refraction of ice is 1.31, which is the value adopted by Bravais and his followers. It is that of yellow-green light, the most brilliant portion of the spectrum. This constant yields 49.76° for the critical angle of interior reflection, 45.74° for minimum deviation for 90° prisms and 21.84° for that of 60° prisms.

In calculating the optical effect of a prism, the prism will be regarded as placed at the center of the celestial hemisphere of which the area within the circle of the horizon is the projection; the aspect of the prism with respect to the celestial sphere will be defined by the positions of the poles of its eight faces. A convenient

[2] John Murray, London, 1821.

notation which will be adopted is the following: o and *o* mark the poles of one base and its opposite; p, p′, p″ give the places of the poles of three successive lateral

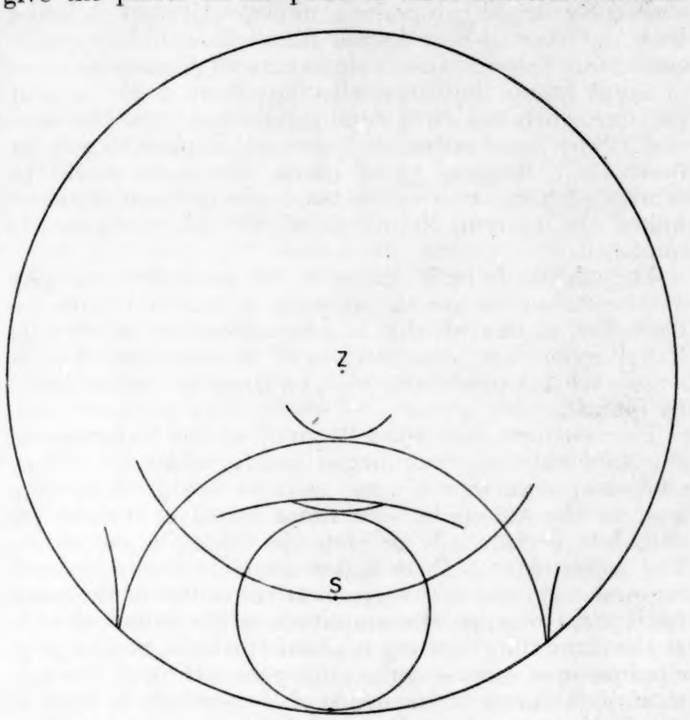

FIG. 2.—Halo of Parry and Sabine drawn in spherical projection with zenith at pole of plane of projection.

faces and *p*, *p′*, *p″* those of their opposite faces, respectively. The spherical coordinates of points on the sphere are the zenith distance, symbol z, and the dif-

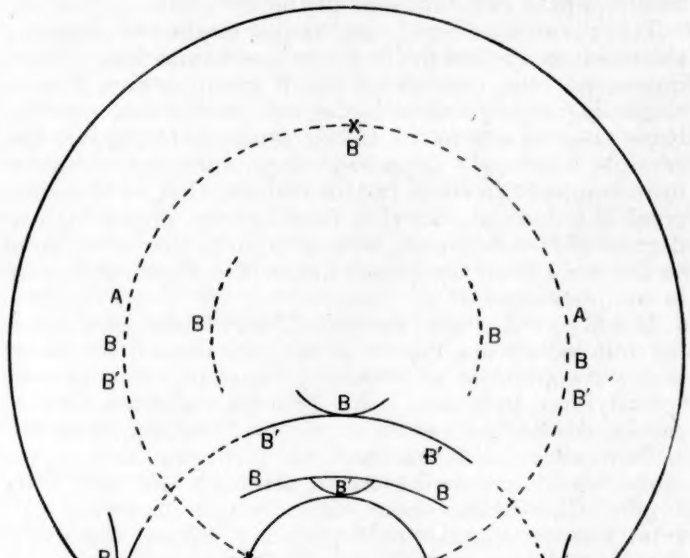

FIG. 3.—Halo of Parry and Sabine according to theory here presented. The letters indicate particular group of crystals involved.

ference in azimuth between that of the point to be defined and that of the sun. The latter angle will be called the amplitude and designated by the symbol u.

The accompanying figure 3 shows the results of such calculations; it includes two features which are outside the limits of the drawing by Parry and Sabine but are described in the text. These are the faint luminous spot opposite the sun in the parhelic circle called the anthelion, and the pair of faint arcs between the zenith and the parhelic circle having a mean amplitude of approximately 90°. The origin of each of the details is indicated by the lettering which shows the group or groups of crystals concerned in its production. The close resemblance between figures 2 and 3, the former being merely a record of eye observations and the latter a mathematical deduction from the fundamental assumptions for a sun altitude of 23°, is a quite sufficient proof that of the groups of crystals assumed all but the A′ group are occasionally effective in causing halos. The proof as regards this last group will appear later.

A somewhat complete analysis of this solution embodied in figure 3 will save many words in descriptions of corresponding features characteristic of higher altitudes.

The effects of the A group are rather insignificant in this particular manifestation for, besides the familiar 22°-parhelia, they only add a small portion of the total light in the parhelic circle and to the inverted arc above the 46°-circle.

The B group, particularly prominent in this halo, although far from rare in other cases, is the cause of the arc whose highest point is about 39.7° from the zenith, equivalent to 5.5° above the vertex of the 22°-circle; of the brilliant spot of light at the horizon which is merely the complement of the preceding feature; of all of the light in the oblique arcs springing from the horizon at the lower ends of the interrupted 46°-circle; of most of the light in the upper tangent arc to the 46°-circle; of the faint arcs between the zenith and parhelic circle which we shall later find cause for denominating the higher oblique arcs through the anthelion; and, finally, to much of the light which comes from the parhelic circle.

The B′ group produces the upper and lower tangent arcs to the 22°-circle, the latter being mostly below the horizon; of the three brilliant portions of the 46°-circle which are tangent to three arcs mentioned above as due to B crystals and, possibly, to the totality of the 46°-circle; of much of the parhelic circle; and, finally, of the faint spot of light opposite the sun in the parhelic circle. These various details of the halo in question will be taken up in the order named, ignoring, however, the 22°-circle, concerning which everyone is agreed.

That the A group is relatively inconspicuous in the Parry halo is proved by the moderate intensity and extension of the 22°-parhelia, very different in these respects from the famous halo of Hevelius. In the latter, which will be discussed later, the presence of the A′ group, here wanting, will be demonstrated.

The crystals of the B group have the upper and lower lateral faces persistently horizontal; in other words, they subside in the atmosphere with a maximum cross-section constantly horizontal. The two basal planes are constantly vertical. Light from the sun which falls upon the upper face, p, will emerge after refraction through the surface *p′*, provided that the amplitude of the pole o of the base is not too far removed from ±90°. A sufficient number of places of images of the sun produced thus with different values of the amplitude of o were calculated so that the long arc depicted between the 22° and the 46° circles could be accurately constructed. Since none of my predecessors has considered this highly important feature I venture to call it Parry's upper arc, and hereafter I shall refer to it under that name.

Light which enters the same B crystals at a p″ face and emerges also at a p' face forms an arc below the sun convex upward and mostly below the horizon. Its vertex is 23° from the sun and very brilliant. At first thought it appears contradictory that the observers noted this as white, but a recognition of the facts that the less refrangible portion of its spectrum is combined with a more refrangible portion of the ordinary lower tangent arc of the 22°-circle, and that the distinctive colors of short wave lengths are invisible on account of falling below the horizon, readily disposes of the contradiction. This arc, which will recur in other cases with a higher sun, will be called Parry's lower arc.

In this particular halo the arc tangent at the vertex of the 46°-circle is chiefly due to the B group, although in many cases only the A group is concerned, as in the Hevelian halo, which follows; indeed, Bravais emphasizes the relation of this arc to the 22°-parhelia inasmuch that they occasionally exist together as the whole of the manifestation. Of course that writer, recognizing neither the A group nor the B group as defined here, but only the elongated prisms assumed to fall with vertically directed axes as providing horizontal rectangular edges, was obliged to regard them as always associated, whereas in this particular halo the association is only partial. However, given such persistently horizontal refracting edges of 90°, the theory of Bravais is complete and the topic might be left without further discussion were it not for a significant remark in the description which is worth consideration. The observers remark extraordinary purity of the colors in this arc when the sun was much lower, although during the earlier period the incidence of the light was almost exactly that corresponding to minimum deviation and maximum brightness. The reason is not far to seek. The visible spectrum produced by a right angle prism of ice is a short one—we may rate it at about 1.5° in neglecting the fainter terminal colors; but the diameter of the sun is much too considerable a portion of this angle to yield a spectrum approaching purity of colors. This effect due to angular magnitude of the source diminished with increasing angle of incidence and the spectrum becomes an absolutely pure one at the limit of 90° incidence. As this effect is reversed when the angle of incidence is less than that proper to minimum deviation it is likely that the arc has been more frequently recorded with excessive incident angles than when the emergence angles were equally in excess.

The curious arcs springing from the horizon and tangent to the 46°-circle come from light which, incident on a base of a B crystal, emerges from a lateral face. It is easy to see that the conditions necessary for their production are very unusual, and they would also be very evanescent, except in polar regions; they have not been considered, as far as known to me, by any previous writer except Bravais, who classed them with certain tangent arcs due to B′ group. In this he was certainly in error, as will appear when I discuss the features attributable to the latter group. They may be called Parry's lateral tangent arcs to the 46°-circle.

A portion of the light which enters the upper face of a B crystal would fall on a basal plane, and after reflection from that plane would emerge from the p' surface. In those cases in which the amplitude of the crystal is such that this interior reflection is total this light is significant. Such is the origin of the arcs near the zenith and drawn as broken lines in figure 3. With a higher sun this feature is sometimes conspicuous and it will be convenient to defer a theoretical consideration until such cases come under review. They may be styled Upper oblique arcs passing through the anthelion.

As a final feature, due in part only to the B group, should be named the parhelic circle. All light reflected from the bases of both groups B and B′ would appear to come from the parhelic circle as also that from the sides of the A group; but especially important would be that portion which has been totally reflected from the interior. Such total reflection ceases at amplitudes not far from 130°. Beyond these limits the circle would be fainter, a character which is not noted in the description unless the extreme faintness of the anthelion clearly implies it.

The effects of the B′ group in the immediate vicinity of the 22°-circle are so perfectly understood from the discussion of Bravais that it is not necessary to consider them further here, especially as all the solutions of these details in this paper are deduced from the tables given by him.

The contributions of the B′ group to the features near the 46°-circle can not be so easily dismissed. They consist of a number of arcs, more or less perfectly tangent to the 46°-circle, sometimes concave toward the sun, but occasionally having the opposite curvature. The conditions of their appearance are easily defined. Suppose a crystal of this group at the center of the celestial sphere; change the amplitude of its principal axis, at the same time rotating it about this axis, until a principal plane of a rectangular edge passes through the sun, then, if the angle of incidence of the sunlight is that, or nearly that, corresponding to minimum deviation there will result an image of the sun at a point in the 46° circle or just outside of it. In this case all crystals having nearly the orientation defined would contribute to the formation of an arc passing through this image no point of which could be nearer the sun, hence the arc would appear to be tangent to the 46°-circle.

There is another highly instructive method of attaining the result as applied to the Parry and Sabine halo. Having shown that crystals of the B group, which have a single degree of freedom as regards orientation, produce three tangent arcs to the 46°-circle and knowing that the crystals which are supposed to produce the 46°-circle have complete freedom in this respect, that is, three degrees, it follows at once that the B′ group, possessing two degrees of freedom, must form arcs more closely adjusted to the circle than the former arcs. The observations are in complete accord.[3]

It will be noted that these three arcs, although departing but little from the 46°-circle, are limited in extent and leave portions of this circle vacant. If, however, we attribute to some of this group a moderate rocking motion about the center of mass of the character described above, this vacancy would disappear and the circle would appear unbroken although not uniformly bright. Calculation shows that crystals departing 14° from the horizontal would perfectly replace the hypothetical random crystals to which the accepted theory attributes the 46°-circle, while half this angular deviation would be quite sufficient to give rise to a ring which could not be distinguished from a circle except by careful measurement. These considerations lead me to prefer this explanation of the 46°-circle to the current one which has long been accepted. It is adequate—even to ex-

[3] The previous theories of these arcs are somewhat tangled. Bravais gives his theory in three lines, a theory which is not clear to me. Pernter rejects this theory and replaces it by another which so acute a critic as Besson finds untenable: nor does the latter theory appear to me to accord with the mechanical laws to which falling crystals are subject or the records.

plaining the unique observation of Besson, who found a visible separation between the circle and the closely-agreeing tangent arc—and also answers the puzzling question as to why the circle has never been seen complete; that is, wholly above the horizon.

There remain the short arcs through the anthelion and the anthelion itself. These I attribute to the action of the B′ group and explain as follows: Imagine a crystal of this kind at the center of the celestial sphere with its p face vertical, the p'' and p′ being respectively above and below it, and the sun near the horizon. Light from the sun entering this face near the end of the prism would, after successive reflection from the vertical base and opposite side in either order, emerge at the surface of entry as coming from a point in the parhelic circle exactly opposite the sun, in short, from an anthelion. This would be true for all angles of incidence, but in those cases where both interior reflections are partial the returning light would be entirely insignificant. On the other hand, when the reflection from the basal surface is total the quantity of light returned would be vastly greater. If, however, the angle of incidence is small the dimensions of the reflected beam of light would be small on account of the foreshortening of the totally-reflecting surface; as this angle increases, the quantity of light would continuously increase until it reached its maximum at the critical angle of interior incidence. With a higher sun, approximating to 30° for example, light entering at the p'' face and emerging, after having experienced a similar double reflection, at the p′ face would also appear to come from the anthelion. But the assumed position of the crystal is not a stationary one according to the mechanical principles governing the falling of light bodies through a resisting medium, hence the effects produced would be less simple than this. In fact, the rotating B′ crystals would yield two arcs passing through the anthelion; the outer edges would be tolerably well defined and much the brightest portions, so that they would appear as two short arcs crossing at the anthelion under a determinate angle depending upon the altitude of the sun. With the sun at the horizon calculation shows that this angle would be about 20°, the angle increasing rapidly with increasing altitude. With the altitude of the sun at 30° the short arcs due to light entering and emerging at different faces the angle of inclination may be rated at 70°. With a certain range of intermediate altitudes both pairs of arcs may coexist, although such occurrences must be infrequent.

A review of the last paragraph shows that the present theory does not allow for a true anthelion, that is, there is no stationary image produced by a host of crystals of widely varying orientations; on the other hand, there is often a brighter portion of the parhelic circle exactly opposite the sun which is the locus of the intersection of three or of five arcs, as the case may be, and which still may bear the name. This node is accentuated by the fact that the short arcs are brightest just at their middle points, which fall on the parhelic circle. Necessary deductions are that these phenomena are only associated with a low sun. The explanation is advanced with some confidence not only because it seems to fit admirably with the records but also because there is no alternative other than one which attributes the arcs to diffraction from highly fantastic crystals which have never been observed and which are supposed to fall edgewise.

The famous halo of Hevelius, observed and recorded by that astronomer in 1661, presents a new set of phenomena. Unfortunately the record is very imperfect, since the drawing and the description are very discordant just where we demand precision. But in the admirable collection of recent observations described by Dr. Louis Besson [4] there is one, a drawing by Orin Parker, of a halo seen by him at Bentonville, Ark., November 1, 1913, which is almost a replica of that recorded by Hevelius except that the paranthelia and the oblique arcs through them are placed in their proper positions, namely, at amplitudes of 120°, plus and minus, respectively. At any rate, the following explanation will rest upon the assumption of the essential identity of the two.

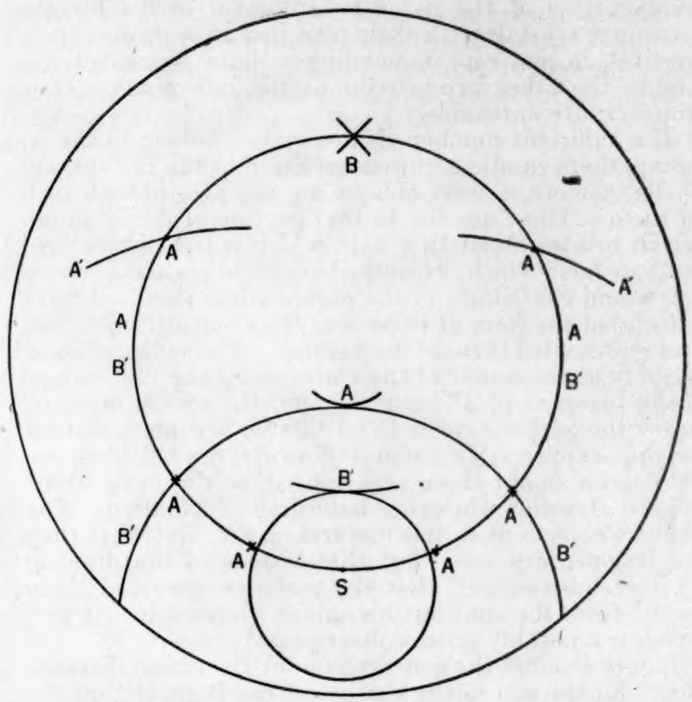

FIG. 4.—Halo as deduced from present theory, similar to that of Hevelius. The B group supposed to be absent. Zenith distance of sun 65°.

Both the halos are characterized by the brilliancy of the effects due to the A type of crystals, the other type being represented only by the B′ group. The evidence in favor of this statement lies in the intense brightness of the 22° parhelia and the absence of all traces of the Parry arcs and of their attendant consequences. As the B′ group produces nothing not already considered in the Parry halo, there is no reason for discussing their effects—the geometric drawing of figure 4 will enable one not only to compare the solution with Parker's drawing, but to find coordinates for all points desired with sufficient precision.

Let an A crystal be placed at the center of the celestial sphere and consider the course of sunlight falling upon it. Most of the light entering the upper surface will emerge from the under surface in an unchanged direction, but a portion will fall upon a vertical face and be reflected—totally reflected if the zenith distance of the sun is not too great—thence, emerging from the lower base, the light would come from some point in the parhelic circle. In many cases, however, a portion of the light reflected from the vertical face would, before being transmitted through the lower base, fall on an adjacent face; such light would also appear to come from the parhelic circle, but from one of two points only, each at 120° from the sun. This assertion does not require proof here because it is contained in the familiar theory of the kaleidoscope, but it is equiva-

[4] MONTHLY WEATHER REVIEW July, 1914, 42: 436-446.

lent to a statement that these common and puzzling features are an immediate consequence of our theory. Nor is it merely a few of the crystals which contribute light to the paranthelia of 120°, for theoretically just half of them are thus involved, although those of importance at any one instant are a smaller portion. It is clear that these paranthelia can not appear when the sun is very near the horizon or the zenith, whence we may fairly conclude that they appear more frequently at mid altitudes, from 25° to 50°, for example, a conclusion wholly accordant with the records. The only other theoretical explanations of the paranthelia known to me involve columnar crystals with their principal axes continuously vertical, in one case demanding stellate cross sections, and in the other two interior partial reflections. They appear quite untenable.

If a sufficient number of the crystals belong to the A′ group, there results a curious addition to the 120°-paranthelia, namely, a short oblique arc passing through each of them. These are due to that portion of the A′ group which rotates about that axis, which is equally inclined to those faces which, when the hexagonal plate is horizontal, would contribute to the paranthelion itself. I have calculated the form of these arcs for a sun altitude of 30° and represented them in the figure 4. The sun appears as sensibly at the center of these arcs, since the 120°-paranthelia being at 97.2° from the sun, the arcs from 21.0° below the parhelic circle to 12° above are more distant by the inappreciable amount of two and a half degrees.

Without doubt these arcs constitute the famous 90° halo of Hevelius which has baffled all explanation. The obvious objections to this declaration are, first, that they are fragmentary arcs—but that is true of the drawing by Hevelius; second, that the recorder described them as 90° from the sun, but his sketch places them at 78°, which is a notably greater divergence.[5]

Figure 4 shows the general halo for the zenith distance of 60° for the sun in the absence of the B group, but the effective presence of the other three; it may be compared with the figures of Hevelius and of Parker.

II.

The first section of this paper may be accepted as demonstrating the occasional existence in the atmosphere of some or all of four groups of crystals, these groups being necessary consequences of the two types of familiar crystal forms which are known to exist. The present section will concern itself with an investigation of the extension of the theory to halos accompanying the sun at higher altitudes. This does not involve a great deal of description, since the illustrative figures are all geometrical, so the amplitude of any point on the diagram can be determined directly, by means of a protractor and the zenith distance, from the formula

$$Z = R\ tg\ 1/2\ z$$

where R is the radius of the circle representing the horizon, Z the linear distance from the center of the circle to the point in question, and z the zenith distance. It will be noted that, as in the preceding projections, the lines show the loci of that particular color corresponding to a refraction index of 1.31 and neglect the angular dimensions of the sun. The modifications necessary to involve other colors and the dimensions of the sun are easily supplied; moreover, I shall give later a list of the uncolored features of halos, the others being prismatic.

[5] One might add to these objections the fact that Bravais has cited three more recent observations of a 90° halo, but I have, by referring to the original sources, persuaded myself that the citations were founded upon misapprehensions. Since one of the references was to the account of Perry and Sabine, printed in full above, the reader may judge for himself in respect to that one.

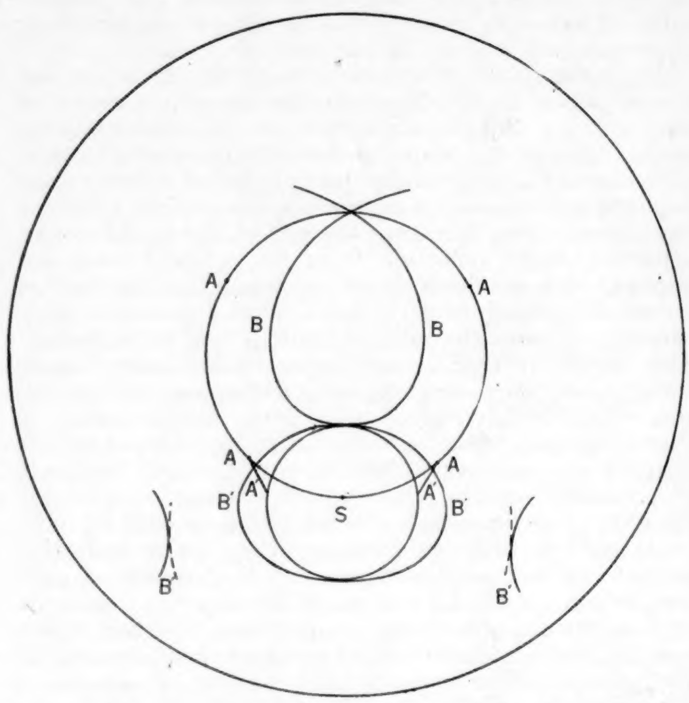

FIG. 5.—A highly developed halo with sun at a zenith distance of 45°, closely resembling the St. Petersburg halo recorded by Lowitz.

Figure 5 shows a possible halo with the sun at an altitude of 45° when all four groups are effective; the 22°-circle is added for comparison, although not necessarily present. The letters attached to each detail indicate the origin with sufficient definiteness with the exception of the pair of long arcs crossing at the anthelion and the pair connecting the ordinary parhelia with the 22°-circle. The former pair I shall style the Upper Oblique Arcs passing through the anthelion, in order to distinguish them from another pair of similar origin which occasionally attend the sun at very high altitudes; the second pair has already been named the arcs of Lowitz from the observer and recorder of the famous St. Petersburg halo of 1790. The long arcs have heretofore been confused with the short arcs confined to lower altitudes of the sun and produced by a different group of crystals, while the arcs of Lowitz have given rise to much theoretical discussion. Let us consider them in the order named.

The upper arcs passing through the anthelion are simply the development of those faint arcs which we found in the halo of Parry and Sabine between the zenith and the parhelic circle. They are produced by light which, falling near the ends of the B crystals and undergoing total reflection, emerges through the same surface as that effective in the upper Parry's arc. The ends toward the sun are at the middle of the latter arc, although it is obvious that it would be impossible to trace them very near that point; they would ordinarily be confounded with the Parry arc, as is so well exemplified in figure 8 in Besson's paper cited above. The theoretical limits in the opposite direction are set by the approach to the critical angle of incidence on the emergent surface, although it is easy to see that the visible limit must be reached before that.

The arcs of Lowitz are of special theoretical interest on account of their extreme rarity with unquestionable authenticity and the fact that theorists have given them

so much attention. According to the theory here presented, they are caused by a certain portion of the A′ group. Such crystals rotate about one of three major diagonals; for suppose a host of such crystals at the center of the celestial sphere and we confine our attention to those of them which when horizontal contribute to the light of a 22°-parhelion. Dominate the face of entry by p and that of exit by p″, then one-third of these crystals will rotate about an axis which causes p and p″ to alter their direction at an equal rate; a second third causes displacements of p and p″ in opposite directions, the latter being at the greater rate, and, finally, the remainder cause displacements of unequal rate but that of p being greater. These may be called the first, second, and third modes. The first mode does not produce a visible effect at this altitude of the sun, but, as shall be proved later, it is the occasional cause of a curious feature with the sun at the horizon. So, too, the third mode is ineffective, but the second mode gives rise to the short arcs connecting the parhelia with the 22°-circle and which are in closest agreement with the record of Lowitz. The fact that the first mode alone produces tangent arcs to the 22°-circle when the sun is at the horizon, while only the second is effective at the altitude of 45° is very suggestive of the reason why these arcs are so rare and are not seen at intermediate altitudes.

At first thought it appears improbable that so small a number of effective crystals could produce a visible effect, but calculation shows that an enormous change in the angle of rotation about the axis shifts the image of the sun along the arc by a very small amount. Thus the condition is an approximation to the "stationary" state of a parhelion and the brightness is correspondingly enhanced.

Aside from these points, the diagram may be regarded as explaining itself except, perhaps, the apparent fragments of the 46°-circle—not always present, it is true—which are attributable to that fraction of the B′ crystals which have a restricted oscillation about their centers of mass.

With a zenith distance much less than that of figure 5 a new feature appears which has been rarely seen in the latitudes of northern Europe but less uncommonly in the United States and which has not yet been discussed. This feature consists of a pair of arcs lying chiefly outside of the parhelic circle but crossing at the anthelion point and from there curving toward the zenith. These arcs have been observed by Lea, Melville, and probably by Meriwether, all of whom are cited in the work by Bravais; but by far the best record known to me is that by H. W. Crawley, described and figured in the Report Brit. Assn. 1861 (2), p. 63. One suspects that only the B and B′ groups were present in this interesting phenomenon and that the circle drawn about the sun was in reality the circumscribing oval, otherwise the darkness within it could not have so impressed the observer. This observation seems to have escaped the notice of meterologists. This feature under discussion is due to the B group of crystals and are therefore complimentary to the oblique arcs exhibited in figure 5. The accompanying figure 6 shows the form which these arcs have when the zenith distance of the sun is 30°. They may be styled the Lower Oblique Arcs through the anthelion since they are produced chiefly by light which emerges from the lower horizontal surface after refraction at a p′ surface and total reflection at a basal surface. The figure shows only these curves due to the B crystals and the ordinary 22°-circle to afford a ready scale of dimensions. It will be recalled that the upper oblique arcs, as shown in figure 5, are due to light which enters the upper horizontal face. In this particular case the inner extension from the anthelion are also due to light entering this face and are therefore properly a portion of the upper oblique arcs. It is easy to state in general terms what the added features would be if the other groups were present. The A group would yield its share of the light to the parhelic circle and possibly exhibit paranthelia, although these would be unquestionably very faint; if the arc below the 46°-circle were apparent, as it often is with the sun at a somewhat greater altitude, this too would be in part due to the A group. The B′ group, if present, would also contribute to the parhelic circle and form a circumscribed oval about the 22°-circle lying very close to it in all its parts.

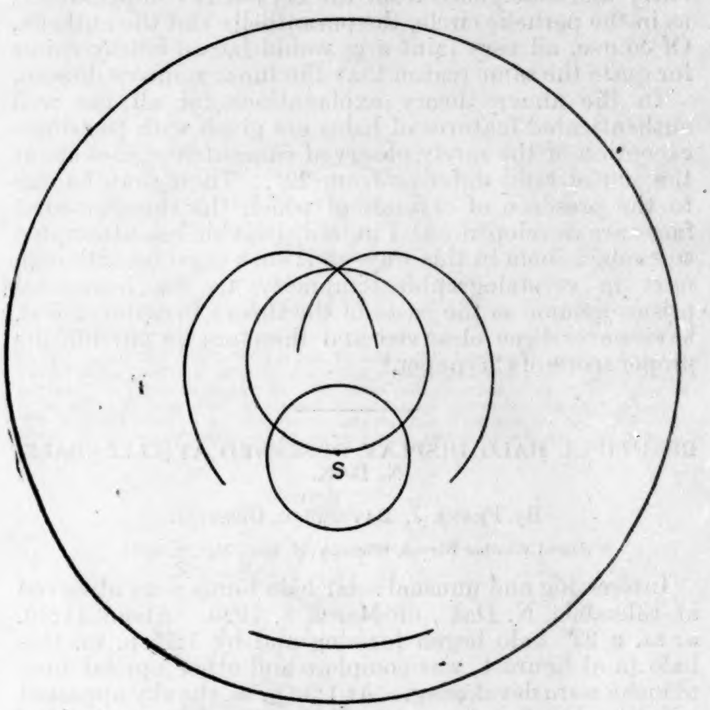

Fig. 6.—A halo due to B group of crystals for 30° zenith distance of sun. The 22° circle is added for scale.

A feature which has a single record is worthy of consideration here, not only because the record is photographic and therefore unimpeachable but also because it verifies the occasional existence of the A′ group in which we have found the explanation of the rare phenomenon of the Lowitz arcs and the Hevelius 90°-arcs.

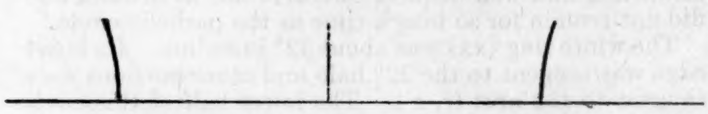

Fig. 8.—Halo of Schultz according to theory. The projection is that of a rectilinear camera so that it may be compared directly with the photograph.

The photograph is found in Archbishop Stuck's "Ten Thousand Miles with a Dog Sled," p. 388,[6] and is here reproduced in figure 7. Figure 8 gives the forms of the curves as calculated on the hypothesis that they are due to A′ crystals rotating on that diameter of the hexagonal plates which is symmetrical to the incident and emergent faces of the crystal. The projection is that of a rectilinear camera, but the scale is altered to

[6] Charles Scribner's Sons, New York, 1914.

agree with the photograph and its center is a point on the true horizon supposed to be the place of the sun. The slight eccentricity of the sun in the photograph is due to a fault of direction in the camera. The fainter vertical column of light directly above the sun is a secondary phenomenon due to these same crystals; in other words, it is the sum of images of the two tangent arcs formed by A′ crystals and, of course, colorless. This is the only certainly established secondary phenomenon excepting the parhelia at approximately 90° right and left of the sun, which are represented in figure 5 above and which have frequently been recorded.

The question as to whether a feature is prismatic or without color is easy to answer from the mode of its production. In general, if produced by refraction we may expect attendant color unless the refraction at entry and emergence from the crystal is compensatory, as in the parhelic circle, the paranthelia and the anthelia. Of course, all very faint arcs would fail to betray colors for quite the same reason that the lunar rainbow does so.

In the above theory explanations for all the well authenticated features of halos are given with the single exception of the rarely observed concentric circles about the sun of radii differing from 22°. These may be due to the presence of crystals of which the rhombohedral faces are developed—and indeed, Bravais has attempted to explain them in this way—but such crystals, although next in crystalographic simplicity to the hexagonal prisms assume as the bases of the theory here developed, have never been observed and therefore lie outside the proper scope of this paper.[7]

BEAUTIFUL HALO DISPLAY OBSERVED AT ELLENDALE, N. DAK.

By FRANK J. BAVENDICK, Observer.

[Dated Weather Bureau, Ellendale, N. Dak., Mar. 22, 1920.]

Interesting and unusual solar halo forms were observed at Ellendale, N. Dak., on March 8, 1920. About 11:30. a. m. a 22° halo began forming and by 1:15 p. m. this halo (a a) figure 1, was complete and other optical phenomena were developing. At 1:30 p. m. the sky appeared as in the drawing, figure 1. The arcs (c, c′) were parts of a circumscribed halo. The 22° halo and these arcs had brilliant spectral colors; the red being nearest the sun. The infralateral arcs (i, i′) were 38° long and extended to 7° above the southern horizon. They had rainbow colors with the red nearest the sun. The large white parhelic circle (mm) was well defined and was accompanied by the oblique arcs of the anthelion (r, r′; s, s′). These were also white and well defined, but were not as distinct and did not remain for so long a time as the parhelic circle.

The white ring (xx) was about 32° in radius. Its lower edge was tangent to the 22° halo and other portions were tangent to the arcs (r, r′). The lower half of this circle was about half as bright as the primary parhelic circle (mm) and the upper half was indistinct, but continuous. The intersection of this circle (xx) and the halo (aa) was very brilliant.

The arc (bb) had faint rainbow colors and was about 22° above the halo (aa). Parhelia (e, e′) were observed outside of the halo (aa) and intensified patches were also noticed at the intersections of (aa) and (c, c′) with (mm).

The disappearance of these circles and arcs of circles occurred gradually between 2:30 and 2:45 p. m. The sky was covered with nine-tenths Ci. St. clouds and they were heavier than the usual type of Ci. St. clouds observed when halos are visible here. No precipitation had occurred for five days, but a low was approaching from the northwest. The surface wind at the time of the halo was from the south, the humidity was 65 per cent and the temperature was −4° C. There was a temperature inversion of about 5° C. at 1,000 meters above the surface.

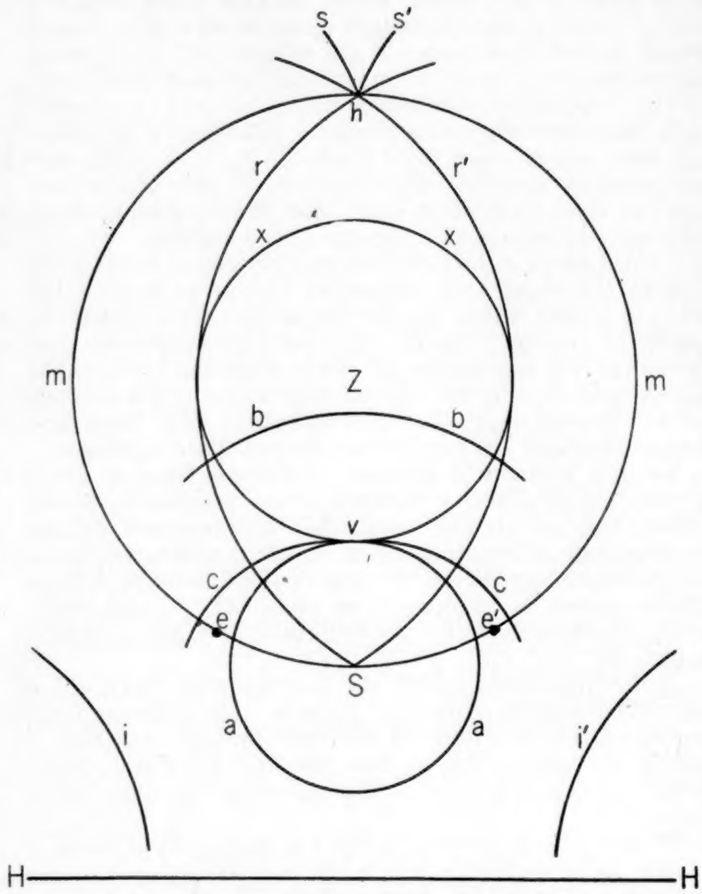

FIGURE 1.—Solar halo phenomena observed at 1:30 p. m., March 8, 1920, at Ellendale, N. Dak., including: Halo of 22° (aa); arc of halo of 46° (bb); arc of circumscribed halo (cc); parhelia of 22° halo (e, e′); anthelion (h); infralateral tangent arcs of 46° halo (i, i′); parhelic circle (mm); two pairs of the oblique arcs of the anthelion (r, r′; s, s′); so-called vertical parhelion of 22° (v); probably secondary parhelic circle (xx). S, sun; Z, zenith; and HH, horizon.

At 3,500 meters the wind was from the west, the humidity about 70 per cent increasing, and the temperature was −15° C.

NOTE.—This description of halo phenomena is of great interest, particularly that portion dealing with the white circle marked (xx). This is presumably what may be called a secondary parhelic circle, induced by the brilliant luminous spot at the summit of the 22° halo; this circle was tangent to the oblique arcs of the anthelion (r, r′). So far as known a complete secondary parhelic circle has never before been observed. In 1896 Rear Admiral A. von Kalmar observed at Pola a portion of this circle,[1] which, if extended, would have been tangent to the oblique arcs of the anthelion.

The observations at Ellendale were made independently by Mr. Bavendick at pilot balloon station "A" and by Mr. Wm. H. Brunkow at the kite house nearby, the angular measurements being determined by means of standard balloon theodolites.

[7] A discussion elucidating some of the more difficult parts of this article will be published in a later issue of the REVIEW.—Editor.

[1] The Different Forms of Halos and their Observation, by Louis Besson. MONTHLY WEATHER REVIEW, July 1914, 42: 444, fig. 20.

Similar phenomena, including some unusual forms, were observed on the same day at other places in the north central portion of the United States. At Lake Okojobi, near Milford, Iowa, for example, there were seen at about 3:30 p. m., among other forms, the oblique arcs of the anthelion, the anthelion of 180°, circumzenithal arc, 22° and 46° halos, circumscribed arcs of the 22° halo, and apparently parhelia of 90°. The circumzenithal arc, visible here, could not be seen at Ellendale owing to the higher elevation of the sun at the time at which that observation was made.—*W. R. Gregg.*

THE BOULDER HALO OF JANUARY 10, 1918.

By EDGAR W. WOOLARD.

A brilliant halo display occurred at Boulder, Colo., on January 10, 1918, some portions of the complex remaining visible throughout the major portion of the day.[1] The writer, through his general interest in natural phenomena, was led to make a sketch about 10 a. m., one hundred and fifth meridian time, when the sun's elevation, as afterwards computed, was 19° 50′.

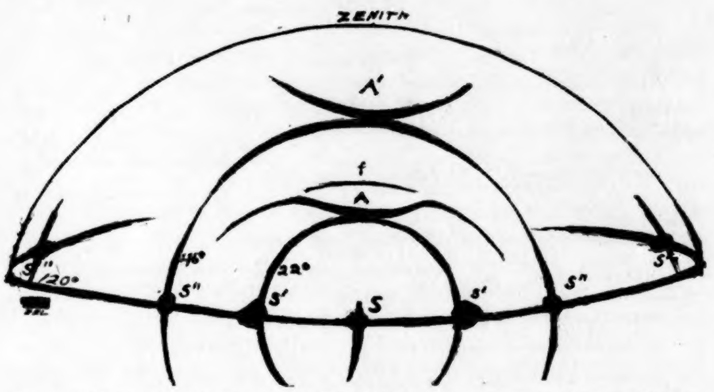

FIG. 1.—Original sketch of the Boulder (Colo.) halo of Jan. 10, 1918, at about maximum development, 10 a. m., one hundred and fifth meridian time.—*E. W. Woolard.*

At that time, the writer was entirely unacquainted with the appearance, nomenclature, and theory of halos, so that the sketch, figure 1, made in pencil on the spot and afterwards inked over, is a perfectly faithful and unprejudiced record of what was actually plainly visible; additional phenomena, not seen because not looked for, probably were present also. It has since developed that this drawing records some unusual features which justify placing it on record.

The most noteworthy features are: The curvature of the sun-pillar, obviously due, as pointed out by Dr. W. J. Humphreys, to a prevailing tilt (eastern edge up) of the reflecting faces, caused, presumably, by gentle surface winds incident to the onset of a cold wave the night before—the atmosphere down to the surface of the earth, was filled with falling ice crystals;—the paranthelic arcs; and the arc *f* between the halos of 22° and 46° and symmetrical about the vertical circle through the sun. This latter arc, previously reported by Parry and by Ferguson, is produced, as Hastings explains,[2] by refraction through randomly oriented ice needles in their most stable position, viz, with a pair of the side faces horizontal.

Figure 2 gives a representation, on the customary conventional "projection," of the halo computed from theory in the usual manner; it will be seen that it is in substantial agreement with observation. It may be helpful to indicate here the method employed to locate

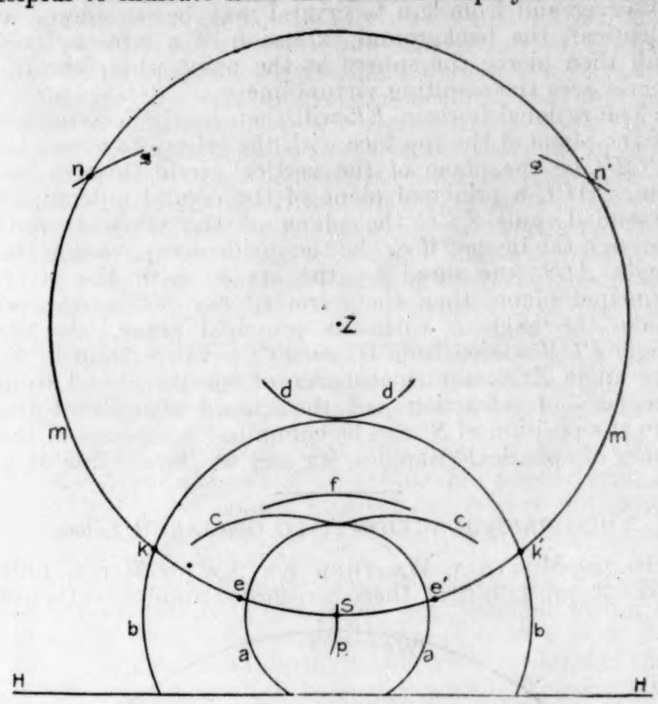

FIG. 2.—The Boulder (Colo.) halo of Jan. 10, 1918.—*HH*, horizon; *S*, sun; *p*, sun-pillar curved owing, probably, to prevailing tip of crystals caused by gentle surface winds *aa*, halo of 22°; *e*, *e′*, parhelia of 22°; *CC*, upper tangent arc of halo of 22°; *f*, "Parry's upper arc"; *bb*, halo of 46°; *k*, *k′*, parhelia of 46°; *dd*, circumzenithal arc; *Z*, zenith; *mm*, parhelic circle; *n*, *n′*, paranthelia; *gg*, portions of paranthelic arc. Elevation of sun, 19° 50′; temperature, —4° F.; air very quiet, and filled with falling ice crystals.

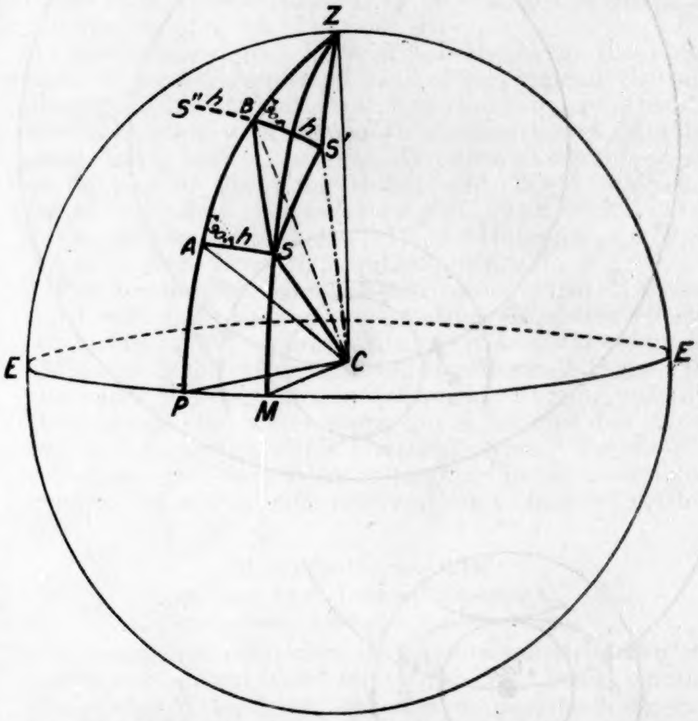

FIG. 3.—*EZE*, celestial hemisphere; *EE*, rational horizon; *C*, observer, and crystal; *S*, sun; *SC*, incident ray; *AC*, projection of incident ray on principal plane of crystal; *ZAPC*, extension of principal plane of crystal; *CS′*, backward extension of refracted ray; *BC*, projection of refracted ray on principal plane; *Z*, zenith: *S′*, image. Although *h* may become as great as *ZS*, internal reflection takes place before this point is reached, thus ending the "Parry arc."

points on the "Parry" arc, since it is one of perfectly general application in such problems, and seems to be about the most direct possible. In figure 3 the crystal

[1] MONTHLY WEATHER REVIEW, Jan., 1918, 46: 22; Science, 47, 170-171, 1918.
[2] MONTHLY WEATHER REVIEW, June, 1920, 48: pages 322-330.

and the observer may both be considered as located at the center of the celestial sphere C, because, owing to the indefinitely great radius of the sphere, rays from sun to observer and from sun to crystal may be considered as identical; the background extension of a refracted ray will then pierce the sphere at the point where the observer sees the resulting virtual image.

The rational horizon EE will then be the intersection of the plane of the top face with the celestial sphere; let $ZSMC$ be the plane of the vertical circle through the sun, $ZAPC$ a principal plane of the crystal indefinitely extended, and $ZS'C$ the plane of the vertical circle through the image; if SC be the incident ray making the angle ACS (measured by the arc h) with the given principal plane, then the refracted ray $S'C$ must also make the angle h with the principal plane. As the angle PCM varies from 0° to 90°, h varies from 0° to the angle ZCS (zenith distance of the sun); and from the laws of refraction and the known altitude of the sun the position of S' can be computed, by means of the chain of spherical triangles, for any assumed value of h.

THE GRAND JUNCTION HALO OF MARCH 3, 1906.

In the MONTHLY WEATHER REVIEW for March, 1906 (vol. 34, pp. 123–124), there is recorded an observation of

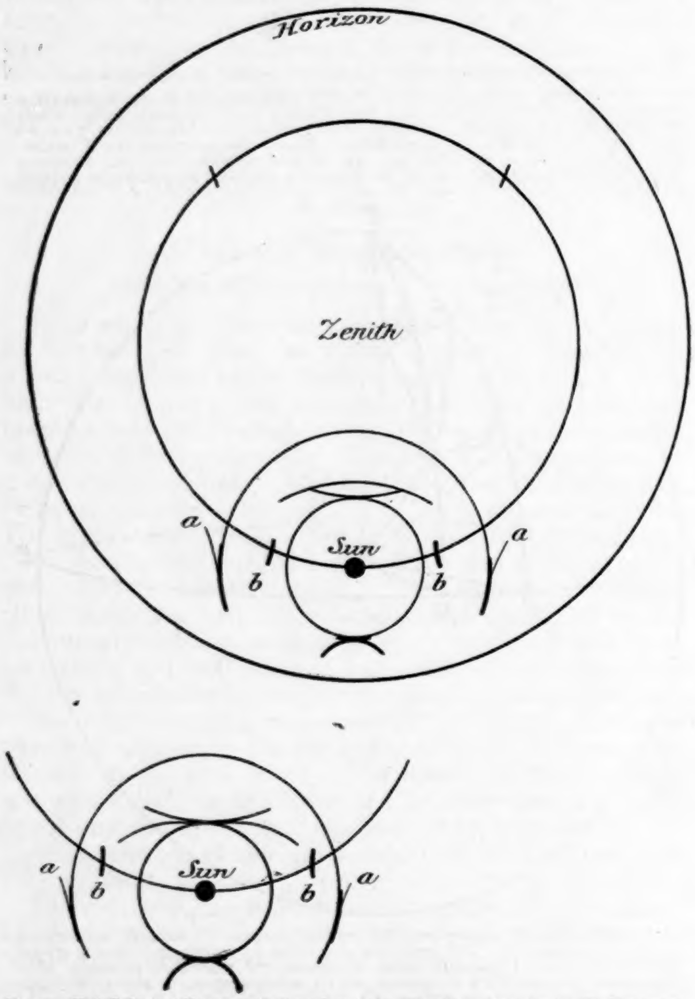

FIG. 1.—Halo observed at Grand Junction, Colo., March 3, 1906, by G. H. Ferguson.

a halo observed at Grand Junction, Colo., on March 3, 1906. The description given there is very meager, but the figures, here reproduced as figure 1, leave no doubt but that the upper and lower Parry arcs were present "The second drawing shows a slight change, there being a difference of about one hour between the two." The times of observation are not stated, and it is clear that the horizon is shown too low in the first figure in proportion to the scale of the halo, because the Parry arc, being produced by the same crystals as cause the upper tangent arc, merges indistinguishably with the latter at a comparatively low solar altitude. In the second figure, the Parry arc has disappeared, and an arc has become visible which is probably the sunward part of what Hastings calls the "lower oblique arcs passing through the anthelion."—*Edgar W. Woolard.*

OUTLINE SHOWING THE FORMATION OF THE ELEMENTS OF A HALO COMPLEX.

By EDGAR W. WOOLARD.

[Weather Bureau, Washington, D. C., July, 1920.]

I.—REFRACTION PHENOMENA.

Orientation of refracting edges.	Phenomena produced.	
	60° angle.	90° angle.
Vertical:		
Minimum deviation	22° parhelia	46° parhelia.
Other deviations	Tails to parhelia	Tails to parhelia. Supralateral and upper bitangent arcs. Infralateral and lower bitangent arcs.
Horizontal:		
Minimum deviation	Upper and lower tangent arcs to 22° halo.	
Other deviations	Upper and lower Parry arcs.	Circumzenithal arc. Circumhorizontal arc.
Inclined:		
Normal to planes through eye and sun—		
Minimum minimorum	22° halo	46° halo (?).
Other deviations	Glare outside halo	Glare outside halo.
In vertical planes through sun.	Arcs of Lowitz[1]	

II.—REFLECTION PHENOMENA.

Orientation of reflecting faces.	Phenomena produced.	
	Partial external or internal reflection.	Total internal reflection.
Vertical	Parhelic circle	Parhelic circle.
Horizontal	Sun-pillar	
Inclined	Oblique arcs of the anthelion (?).	
Multiple reflections	Anthelion and oblique arcs of the anthelion (?).	
Reentrant angles	120° parhelia (?)	

III.—MISCELLANEOUS.

Processes.	Phenomena.
Combinations of refraction and reflection	"Upper and lower oblique arcs passing through the anthelion." 120° parhelia (?). Paranthelic arc (?). Kerns arc (?). 90° halo (halo of Hevelius). 136° halo (Bouguer halo, false white rainbow).
Miscellaneous	90° parhelia. Vertical parhelia. Mock suns. Extraordinary halos. Secondary halos.

[1] See, however, S. Fujiwhara, On the Theory of Lowitz's Arc, Proc. Tokyo Mathematico—Physical Soc., ser. 2, vol. ix, pp. 502–515, 1918.

SIMULTANEOUS OCCURRENCE OF HALOS AND CORONAS

Dr. C. F. Brooks, in a short article published in the MONTHLY WEATHER REVIEW, January, 1919, **47**; 21, cites several cases in which lunar halos and coronas were visible at the same time. Starting with the assumption that coronas originate only from clouds formed of liquid particles, he admits that halos are due to clouds formed of solid particles; these, falling through an atmospheric stratum relatively warm, will pass into the liquid state; whence the origin of the corona. The author does not consider the possibility of supercooled water, nor the formation of coronas by transparent ice crystals.

The simultaneous occurrence of halos and coronas is a more frequent phenomenon than might be thought. In my researches on the frequency of halos I have found numerous cases of such simultaneity. But already Pernter in his "*Meteorologische Optik*," p. 424, cites 16 cases from observations from Ben Nevis, and 4 cases from the expedition of the "Belgica."

It is not necessary, therefore, to form any special hypotheses as to the physical state of the water, as Pernter demonstrates in the same work, p. 395,ffg., coronas may also form in clouds made up of particles in the solid state.—*Carlo Negro*, Torino, Italy. [Translation by *R. S. H.*]

Discussion.—Since the finest coronas are produced on clouds having temperatures far below the freezing point of water, Pernter assumed that such coronas were formed by the diffraction due to ice crystals. Simpson has pointed out, however (*Quar. Jour. Roy. Meteorological Soc.* 1912, **38**, 291–301), that the observations of the Ben Nevis and other meteorological logs referred to by Negro are merely cases in which coronas and halos were entered together, they do not prove that both were produced by one and the same cloud. Careful observations by Simpson while in the Antarctic failed to reveal a single instance in which a corona and halo were seen on the same cloud. Furthermore, his observations of a fog bow prove conclusively that liquid water droplets can exist at −29° C., and there is no reason to believe that this is the lower limit; hence the high clouds on which coronae are observed do not necessarily have to consist of ice crystals. In addition, Simpson shows that ice clouds could not produce coronae at all, merely white light.

Some instructive notes on the existence of minute undercooled *liquid* droplets in the atmosphere, and their relations to crystallization, will be found in *Symons's Meteorological Magazine*, 1917, vol. 52, pp. 17–18, 31–32. (In this connection it may be stated that the present writer has been informed by a competent crystallographer that certain minerals are known in which the surface tension so far overbalances the force of crystallization, even in finite crystals, that crystals with plane faces can not be produced, and in one instance solid *spherical* crystals were obtained.)

It is evident, therefore, that the simultaneous appearance of a halo and a corona requires some special explanation, as in the observations cited by Brooks. This problem, it should be noted, is totally distinct and different from that treated by S. W. Visser in a very important paper "On the diffraction of the light in the formation of halos," Kon. Ak. van Wetensch. te Amsterdam, *Proc. Sec. Sci.*, 1917, 19, pt. 2, pp. 1174–1196 (See abstract in MONTHLY WEATHER REVIEW, 1918, **46**, 22.)—*E. W. Woolard.*

Additional note.—The simultaneous occurrence of a solar halo and corona, or coronae, does not appear to be a rare phenomenon when two or three layers of clouds are involved.

In fact, the frequency is nearly as great as the frequency of halos, although not usually observable without dark glasses or mirror, and, therefore, seldom noticed, and even less often recorded. Occasionally, once or twice a month, a halo may be seen in cirro-stratus cloud, the lower portions of which envelop a corona-forming alto-cumulus layer. The halo may be complete, or nearly so, and with practically undiminished brilliance where it passes in front of alto-cumulus masses; and the denser parts of the alto-cumulus layer cast long shadows down through the cirro-stratus. Although such a halo and corona are not in the same cloud, one cloud and part of the other occupy the same space.—*C. F. Brooks.*

NOTES ON IRIDESCENT CLOUDS.

By S. FUJIWHARA and H. NAKANO.

[Abstracted from Journal of the Meteorological Society of Japan, June, 1920, vol. 39, No. 6, pp. 1-9.]

Pernter's theory of the diffraction of light by ice crystals would be valid if all the needles were so arranged that they had a definite direction, such as would happen if the cloud had some acceleration; this would, in general, be pretty rare, however.

Although the minute drops necessary for Simpson's theory of iridescent clouds are not included within the limits of sizes assigned by Pernter ($1\times10^{-3}<r<5\times10^{-3}$ cm.), the generalization by which Pernter derived these limits does not seem to be sound; and A. Wegener (*Met. Zeit.*, 1910, p. 354) has shown the possible existence of drops of radius 10^{-7} cm. If undercooling can take place to the extent postulated by Simpson, then the latter's theory can be correct. The irregular distribution of colors in iridescent clouds may be due to the irregular distribution of drops of various sizes.

Calculations of the lines of iridescence in the ideal cases of circular clouds and band clouds indicate that all observed hemming and crossing of clouds by color bands may take place with the proper distribution of suitably sized drops, such as presumably exists along the edges of forming or dissolving cloud. (See G. C. Simpson, *Quar. Jour. Roy. Meteorological Soc.*, 1912, 38, 291–301; C. F. Brooks, note below; W. J. Humphreys, *Jour. Franklin Inst.*, Nov., 1919, pp. 654–655.)

Furthermore, the cloud of vapor arising from a vessel filled with hot water shows beautiful diffraction effects when illuminated by sunlight, at angular distances up to 45°, proving the existence of sufficiently small drops. In this vapor, as along the edges of quickly forming (usually thin) clouds, the water drops are in an unstable state, and uniform in size within stratified layers. The violent turbulence, and formation of large drops, in a cumulus head explains why such colors are not observed in this case.—*E. W. W.*

IRIDESCENT CLOUDS.

By CHARLES F. BROOKS, Meteorologist.

[Weather Bureau, Washington, D. C., June 26, 1920.]

Forming, lenticular clouds often show well-defined alternating reddish and bluish or greenish color bands parallel to the edge of the cloud, the innermost portion being perhaps lighted with a greenish or reddish sheen, or perhaps both irregularly intermingled, over a relatively large area. These colors are usually most brilliantly developed within 30 degrees of the sun but at times (as at Washington, D. C. at 2:05 p. m. June 23, 1920) may be discernible to a distance of more than 50 degrees.[1]

[1] Faint diffraction color bands were observed parallel to the edge of a lenticular cloud, about 55° from the sun, at 6:30 p. m., July 26, 1920.

Diffraction, which forms the well-known coronas about the sun and moon, will for droplets of a certain size produce alternating red and blue rings to considerable angular distances from the luminary.[2] Recently I saw a solar corona with a set of four brilliant red rings at roughly equal intervals and interspersed with bluish rings. The larger the droplets, the smaller is the angular interval between successive rings of the same color and the smaller is the first ring around the sun or moon. Also, for any size of droplet, the angular interval between successive red rings decreases with increasing distance from the sun or moon. When the droplets are very small, as they must be in the lenticular clouds, the width of each red or blue ring is several degrees because the successive interference bands are so far apart. Thus an ordinary lenticular cloud may lie wholly within a red or blue band for very small drops. On the thin, sharp edge of the cloud where condensation has just taken place, the drops must be exceedingly small, and probably much the same size all along the edge around the cloud. For drops of this size at the distance of this cloud from the sun the diffraction band, say, is the third red one. Just inside of this cloud edge the particles have been formed for longer and have had a chance to grow to a larger size. For their size and this distance from the sun, the diffraction band, the fourth one (just beyond the third red), is blue. A little farther into the cloud the drops are still larger and are in the fourth red band for that size of drop. The central part of the cloud has still larger drops that fall in the fifth blue band. Therefore, the outer edge of the cloud has a rim of red, next comes a strip of blue and then another strip of red, while the central portion of the cloud is bluish and greenish.

The irregular intermixture of colors on the brilliant margin of a forming cumulus cloud may be explained on the same basis. The droplets just forming are not so large as those that have formed a few minutes before, and, therefore, while the angular distance from the sun may be such as to put this portion of the cloud in a red band for the droplets just formed, those a little larger even though they may be at the same angular distance from the sun are in the next blue or green band.

[2] See W. J. Humphreys, Optics of the Air, Jour. Franklin Inst., Nov., 1919, pp. 654-655.

MEASUREMENT OF WATER IN CLOUDS.

By L. F. RICHARDSON.

[Abstract from Proceedings of the Royal Society, Aug. 1, 1919, Series A, vol. 96, No. A674, pp. 19-31.]

Three types of clouds can be measured: I. Clouds into which an observer can enter. Several observers, notably Conrad and Wagner, have measured the water in clouds on mountains by drawing a measured volume of atmosphere over absorbing substances.[1] II. Clouds through which the sun's outline can be seen and which also exhibit coronae, as they often do. III. Uniform stratus, provided that some way can be found for measuring the size of the particles.

The second type of clouds has been investigated by means of a photometer which measures the variations of intensity of the sun's light in passing through cloud layers of different intensity. It has been suggested that the distance of visibility of an object through a mist is proportional to the diameter of the water particle. Conrad estimated that a terrestrial object was just visible when its intensity was about 1/77 that in clear air. This ratio of brightness of the object to its surroundings is represented by I/I_o. The observational results show that in various intensities of clouds through which the sun's disk could be seen, the volume of particles per horizontal area, the diameter of the particle, or $-2/3 \cos \zeta \log_e (I/I_o)$, is as follows; where ζ is the sun's zenith distance:

Description of cloud.	Volume of particles per horizontal area (diameter of particle).
Faintest cirrus	0.07.
Very thin cirrus	0.3, 0.3.
Ci or ci-stratus	0.04.
Very thin ci-stratus	
Ci-stratus, thin	0.06, 0.2, 0.8, 0.3, 0.5, 0.3, 0.8, 0.6, 0.4, 0.4, 0.8.
Ci-stratus (typical?)	
Ci-cumulus	0.6.
Ci-cumulus+ci-stratus	0.8, 0.9, 2.1.
Alto-cumulus	0.5.
Stratus, sun much dimmed, but still obvious at $\zeta=40°$.	2.5.
Stratus, sun's disk just visible at $\zeta=49°$.	4.1.

It is pointed out that diffraction should be considered before this result can be relied upon.

In the case of heavier clouds, it is necessary to make use of the amount of transmitted light and the reflectivity of the earth's surface. In the case of certain rain clouds on the afternoon of May 24, 1918, it was found that the volume of liquid per horizontal $cm.^2$ of cloud amounted to 24 diameters of the cloud droplets. This, it will be noted, is in accord with the observations of thinner clouds in the table above.—*C. L. M.*

[1] The first type is discussed by Hann's Meteorology, third edition (1915), p. 306. The moisture was obtained by drawing known volumes of air over absorbing substances, such as calcium chloride or pumice stone saturated with sulphuric acid. It was found in this way that in various types of clouds on mountains the moisture content varied from 1.6 gram per cubic meter, where it was possible to see 50 meters through the cloud, to 4.5 gram per cubic meter where the radius of vision was limited to 20 or 25 meters. It was found that when the water particles are about 0.01 mm. in diameter, and the water-content of the cloud is from 1 to 2 grams per cubic meter, the number of drops is between 200 and 500 per cubic centimeter.—C. L. M.

SOME OBSERVATIONS ON A FREE-BALLOON FLIGHT MADE FROM ABERDEEN PROVING GROUND, MD., JUNE 3, 1920.

By DON MCNEAL, 2d Lieut. Meteorological Section, Signal Corps.

As a part of the course in pilots' training, a free balloon flight was made from Aberdeen Proving Ground, Md., June 3, 1920. Existing and indicated meteorological conditions on this day gave promise of anything but ideal weather for a flight of this kind. For three days preceding, this section of the country had watched the slow eastward drift of a trough of low pressure from the west and northwest, which had been attended by general rains and thunderstorms. On the morning of the 3d, the center of the trough extended from the St. Lawrence Valley southwestward over New York, Pennsylvania, West Virginia, Tennessee, and on to the Gulf.

The day opened fair, with only a few Ci.St. and A.Cu. clouds visible. These forms were moving from the west and southwest respectively. The pilot balloon observation, taken at 7:29 a. m., showed a west surface wind, veering quickly into WNW. and NW. winds, and above 8,500 feet, backing again into the west. The velocities were moderate at all levels, increasing only slightly with altitude.

The temperature mounted rapidly throughout the forenoon, and it appeared that the highest readings of the season would be recorded.

At 9:45 a. m. cumulus clouds were first observed in the northwest, drifting slowly from the WNW. At this time, the surface wind was shifting between W. and NW., with moderate velocities.

A second pilot balloon observation was made at 1:09 p. m., which indicated a backing of the wind from NE. at the surface, through N., NNW., NW., WNW., becoming W. at 6,000 feet. The velocities were low and increased only slightly with altitude, being but 17 miles per hour at 7,000 feet. At this time, large towering thunderheads could be seen moving upon the station from the NW., while others appeared to be passing some distance to the north.

The seeming assurance, which a digest of the above observations gave, of encountering all the adverse conditions incident to piloting a balloon through thunderstorms, was weighed. Also the possibility of danger from lightning was considered. However, the enthusiasm of the pilot and observers would not be denied and the balloon left the ground at 1:59 p. m.

True to the results obtained from the pilot balloon observation, we drifted off to the southward, and, with rapidly gaining altitude, moved slowly into the SSE. At the end of the first five minutes, an altitude of 2,000 feet had been reached. The temperature here had fallen from 31.3° C. at the surface, to 28.2° C. The atmosphere was very hazy to the south and southwest, while showers were observed a short distance to the north-northwest. At 2:09 p. m. an altitude of 2,340 feet had been reached and we were nearing the edge of the Chesapeake Bay. The sun was obscured and the balloon was under a heavy cumulus cloud. Difficulty was being experienced in gaining altitude, due to contraction. Thunder was first heard in the north at 2:12 p. m. At this time, it was thought best to go above the clouds to lessen the danger from lightning and, also, to endeavor to strike the westerly wind with greater velocity. The absence of sunshine, however, made this operation difficult, and required the expenditure of much ballast. At 2:14 p. m., an altitude of 2,900 feet had been reached, and we were going more nearly southeastward and approaching close to the edge of the bay. The thunder was sounding nearer and the rain appeared almost upon us. During the next several minutes, while over the bay, and with the sun hidden, constant difficulty was being met in maintaining altitude. At 2:44 p. m., we had fallen to 2,000 feet, and were over the bay and opposite the mouth of the Sassafras River. At this point, rain was heard striking the balloon. At 2:49 p. m. we were down to 1,100 feet and had moved inland south of the river. Ballast was used freely here and we began rising rapidly. The rain had stopped for a short time, but at the next observation we were in the midst of a large Cu.Nb. cloud and the rain was beating down hard. Thunder was plainly heard, although no lightning was observed. We had lost sight of the ground and were still rising rapidly. It appeared as though our position within the cloud was operating to accelerate the already rapid ascent. The vertical movements of cloud sections were readily discernible. At 3:04 p. m. we had reached 5,220 feet and appeared now to be at the edge of the cloud. Towering above us many hundred feet, we could see the great thunderheads still piling upward.

Some openings appeared above us revealing the presence of a layer of thunderstorm cirrus. The sun was now shining on the balloon, sending us still higher. The temperature while within the cloud had been down to 19.4° C. This now rose rapidly to 28.0° C., due both to direct sunlight and to that reflected from the clouds beside us. At this point our attention was attracted by moderate sized hailstones passing down past the balloon. The observation of this phenomenon would seem to agree with the theory of the formation of hailstones, which provides for their formation in the upper portions of the Cu.Nb. in preference to the theory for their formation in the squall cloud. Certainly this observation was made at a considerable distance above the level of the squall cloud; also, the temperature observations would preclude the possibility of hailstones forming at this or lower altitudes. Undoubtedly, the hail which we observed was issuing from the cloud a considerable distance above the balloon.

We were still gaining altitude at 3:09 p. m. and had encountered a moderate northwest wind which was carrying the balloon inland. About 3:22 p. m. the balloon reached the maximum altitude of the flight—8,200 feet. Shortly after this we were again within the cloud. Loud thunder was heard and it was raining hard. We now began to descend rapidly. At 3:34 p. m. we were down to 4,850 feet and still falling. Much ballast was expended in an effort to check the descent, but due to the rain and gas contraction we were unable to establish an equilibrium. We were now drifting toward a wooded ravine and a good landing did not appear possible. Our ballast was being rapidly depleted, but with only momentary relief from the unwelcome proximity to tree tops. By this time the drag rope was catching in the branches, sometimes stopping the balloon for a minute or two. From the basket the balloon now gave somewhat the appearance of a parachute. This, added to our lack of ballast, prevented our escape from this position. After each freeing of the drag rope the balloon only drifted farther down the ravine, until finally the rope became securely entangled in the top branches and held us fast. There was very little wind movement at this time and we were prevented from settling in the trees only by grasping the top branches in our hands and holding our balloon up.

We were soon rescued, however, by several farm hands, summoned from a nearby road, who cut the drag rope from the tree. We then drifted to the edge of the wooded area and valved down in the corner of a grass field, about 3 miles west-northwest of Kennedyville, Md., being an air-line distance of about 30 miles from the starting point.

Thus ended what was agreed upon by all participants as a balloon flight crowded with interesting observations and experiences.

The balloon was piloted by First Lieut. H. H. Holland, while Maj. J. C. McDonald and Second Lieuts. E. C. Cooke and Don McNeal were the observers.

EFFECT OF WEATHER ON THE AERIAL MAIL SERVICE.

Interesting notes regarding the reliability of the aerial mail service have appeared in the *Aerial Age Weekly* and the *U. S. Air Service*. In its issue of April 5, 1920, the former presents a report for the eight months preceding April. Among other points mentioned in the report is the number of forced landings on account of weather conditions. During this period there were 1,111 trips with a total of 203 forced landings, of which 47 were attributable to mechanical trouble and 154 to the weather. The latter magazine (July, 1920) reports for

the month of May for routes between New York and Washington, New York and Cleveland, Cleveland and Chicago, Chicago and Omaha. In all, 54,693 miles were flown. Two forced landings were made on account of mechanical troubles, fifteen because of running out of oil or gas in combating head winds, four on account of bad weather, and seven because of the lack of familiarity of new pilots with the course. In the eight-month report 75 per cent of the forced landings are attributable to the weather, and for the month of May 68 per cent. While it is true that the actual number of forced landings is small, considering the number of miles flown and the rigorous schedule which is maintained by the mail service, nevertheless, these reports emphasize the dependence of the aviator upon weather conditions.—*C. L. M.*

DAYTIME WIND TURBULENCE IN A MOUNTAIN VALLEY.

By B. M. Varney.

[University of California, July 15, 1920.]

SYNOPSIS.

An unusual example of wind turbulence in the daytime air stream in mountain valleys is found near Yosemite Valley, Calif. The stream as it flows east up the valley in the afternoon divides through two branch canyons, the current in the southeasterly branch turning sharply round a steep mountain spur. This spur and the configuration of the canyon walls sets up a rotation of air in the lee of the cliffs about an inclined axis, the lower end of which is at the spur, the upper end about a mile away to the east, the general trend being parallel to the side of the canyon. The path of an air particle near the periphery of this roll was found by observations on the drift of tissue papers, to be that of a great spiral, the diameter of which seems to vary from nothing at the spur to perhaps 2,000 feet at the east end. Observed variations in the form of the spiral are due to changes in the local winds under the influence of topography.

Paper pie plates do not ordinarily lead to even casual studies of winds in mountain valleys. They are not commonly thought of as anemoscopes. In Yosemite Valley, Calif., in the early afternoon of June 8, 1920, however, a certain pie plate, having presumably functioned in the manner common to pie plates, suddenly and under circumstances unknown to the writer, assumed the role of an anemoscope and led to an hour's most interesting study and to the discovery of a wind phenomenon not hitherto observed by the writer.

Yosemite Valley, trending in a general east-west direction, branches at its upper eastern end into two valleys, Tenaya Canyon toward the east-northeast and the canyon of the Merced River leading by two right-angled turns, first south a half mile and then east a mile up a steepish gradient to Little Yosemite Valley, which penetrates the Sierra Nevadas in a general east-southeast direction. Between the two branches stands a mountain mass of which Half Dome, 4,892 feet above the main valley floor, is the dominating feature. The daytime stream of air up the Yosemite Valley, of course, splits against this mountain mass, the stream into the Little Yosemite being forced through the narrow and crooked canyon of the Merced River. At the second turning (south to east) the stream passes round a sharp and steep spur which stands like a slanting door post in the reentrant angle of the canyon, and past which the wind on clear, warm summer days often whistles with gale force. This sudden turn, together with the configuration of the corner as noted, appears to be responsible for the extraordinary turbulence to be described.

The writer was on a jutting point on the spur some eleven hundred feet above the valley floor, from which point the accompanying eastward-looking sketch was made, when suddenly a paper pie plate came swirling up from below in a vertical suction current in the lee of the spur. In a twinkling the rushing current aloft, turning round the mountain spur, caught the plate and hustled it off upward and eastward. Thus began the flight. It was easily traced, first with the gray cliffs as background and then a clear sky. Presently the plate began to draw away from the cliffs, rose, and describing a gigantic arc toward the middle of the valley, finally got into a downward rush at a speed far too great to be due to the simple action of gravity on the plate in still air. This looked like the end of the flight. When, however, the plate seemed about to be lost in the forest at the bottom, its flight gradually turned into a rush at high speed over the tree tops eastward up the valley, then into an ascent toward the north valley wall, then into another swirl aloft close to the rocks, like the first, another drawing out over the valley, another descent until again it seemed as if the flying plate must "crash," but then another run up the valley as before, turning again into a flight upward along the rock wall and ending out of sight behind a mountain spur nearly a mile away (Mt. Broderick in the sketch).

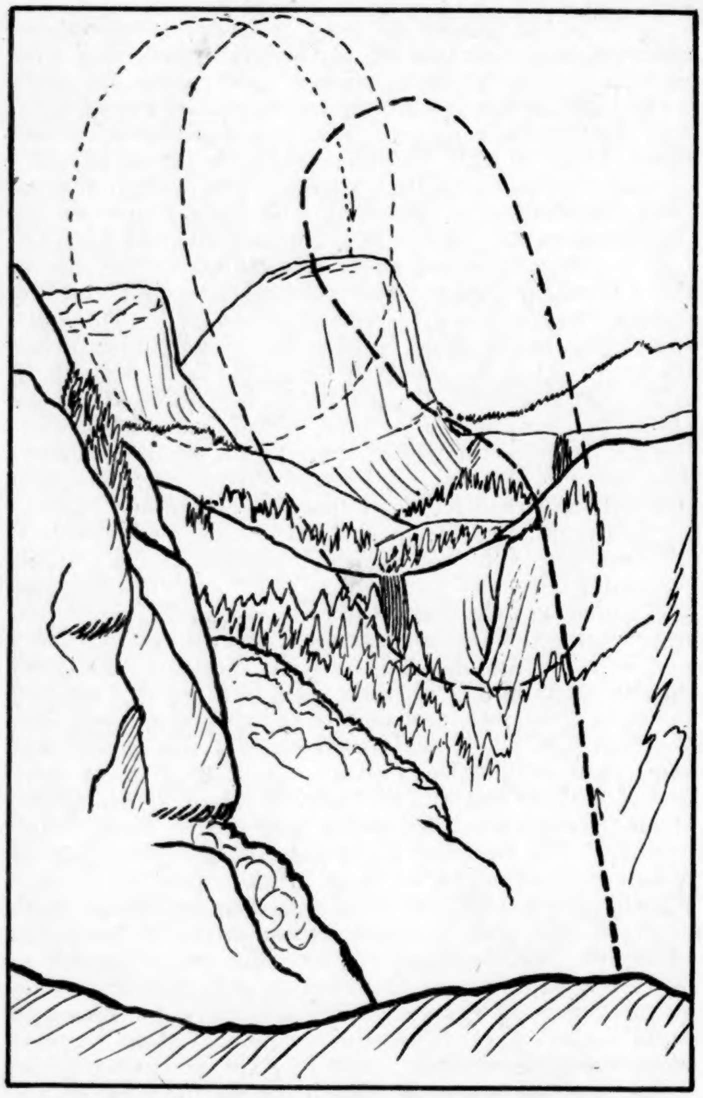

FIG. 1.—Path of paper-flight observed from Sierra Point, Yosemite National Park, early afternoon of June 8, 1920, looking east. North side of canyon of Merced River on left. Vernal Falls in middle distance, ½ mile away. West face of Mount Broderick, left distance, $\frac{3}{10}$ mile. Nevada Falls (right), $1\frac{1}{10}$ miles. Summit of Liberty Cap, $1\frac{1}{10}$ miles. The top of the first turn in the spiral, estimated to be about 500 feet above point of observation: top of last turn, over Liberty Cap, estimated at about 2,500 to 3,000 feet (the latter estimate being based on the fact that the summit of Liberty Cap is 1,600 feet above Sierra Point, and that the face of the sheer cliff extends about 1,300 feet below the summit). Sketched from a photograph taken by the writer.

The feat was so remarkable that the writer spent the ensuing hour and more in launching broad sheets of waxed tissue paper in an attempt to learn if the huge spiralling current thus discovered were permanent. For the papers, very thin and light, undoubtedly indicated closely the courses of air particles as they varied with the different "flights." More than a dozen flights were made, some of them so long that the papers were followed with some difficulty even with the help of six-power binoculars. Every flight showed more or less strikingly the spiralling path first noted. The number of complete turns made varied from one to three, the time of flight from about five to about eight minutes, the horizontal distance travelled from a few hundred feet to over six thousand. The most remarkable flight, which the accompanying sketch is intended to illustrate, lasted nearly seven minutes, covered the greatest horizontal distance in three rotations along the spiral, and ended, so far as could be seen, more than six thousand feet away with a descent from the blue behind Liberty Cap. The top of this peak is some sixteen hundred feet above the point at which the flight began. There is no question but what the spiralling motion thus observed, and which involves the rotation of a huge mass of air about a more or less horizontal axis, is a persistent phenomenon here on warm afternoons.

The axis of the roll lies roughly parallel to the north wall of the canyon and seems to slope rather sharply upward toward the east. Its diameter increases greatly with increased distance from the corner of the canyon where it begins; for the papers almost without exception flew higher on successive turns, while they reached nearly the valley bottom at each descent. This is due to the fact that the valley wall increases in height from the corner eastward. The roll occupies the north side of the valley only, since in their ascents all the papers passed close to the cliffs, or in other words close to the periphery of the roll, and in their descents never crossed the river to the south side. What the conditions were on the south side was not apparent.

The shapes of the courses of air particles along the spiral may be likened to the varying forms which a watch spring would take if drawn out in a more or less elongated spiral. The exact form of the courses indicated certainly depends on at least three factors: First the speed of the general air current up the canyon; second, the variations in the upward suction effect in the lee of the door-post spur, induced by variations in the strength of the overpassing current of the general stream; and third, the rather active heating of the north rock wall by the sun on clear days, with consequent rise of air. In cross section the spiral seems asymmetrical, the horizontal axis being considerably shorter than the vertical. A part of this is apparent rather than real, due to foreshortening; but not all, for the upward flights often carried the papers so high that they were followed with difficulty, flashing in the sun as they were, even with the aid of the glass, while as before noted they never crossed the stream to the south, which is horizontally less than a thousand feet from the upper cliffs on the north side of the canyon.

There was no observable constancy of relation between the number of rotations about the axis of the spiral and the horizontal distance or the time of flight. Some of the longer distance flights showed the smaller number of rotations, while short-time flights sometimes had the maximum number of rotations.

This vast spiral may presently make interesting flying for some venturesome air man, occupying as it does something less than half the cross section of a narrow canyon, up which sight-seeing and mail service by air to Merced Lake and Hotel may conceivably be put in operation. Flying a few hundred feet north of the Merced River probably would lead to trouble with the strong descending current there observed. By hugging the north wall of the canyon precarious advantage might be taken of the lively ascending current there to make a thousand or more feet of altitude in a few seconds, though the danger of the wing tip next the cliff being caught in more rapidly upward moving air than the other, and of serious consequences when the plane was caught suddenly in the upper current above the cliffs, might be considerable. The safer flying will undoubtedly be done on the south side of the river, or, indeed, well above all the canyons and crags with their turbulent air currents.

Not the least interesting item to the writer in observing the paper flights was the air battles waged by the swallows (?) against these strange invaders of their mountain air lanes. Each paper as it wheeled on its course became the object of violent attack by the excited birds, who continued their darting thrusts until distance left only the flashing papers visible.

A FOG PHENOMENON OF SAN FRANCISCO BAY.

By B. M. VARNEY.

[University of California, July 21, 1920.]

SYNOPSIS.

Occasionally when ocean fog is covering the land and the Golden Gate west of San Francisco Bay, a local fog bank [1] forms along the eastern shore of the bay while the rest of the region remains clear. Conditions of air and water temperature and of topography being seemingly unfavorable to the formation of fog in this zone, it is suggested that the fog may be due to forced rising of the humid westerly wind over convection currents, themselves cloudless, on the plain east of the bay, condensation resulting from this forced rise. This local fog bank disappears in the latter part of the day, due to the breakdown of the convection currents.

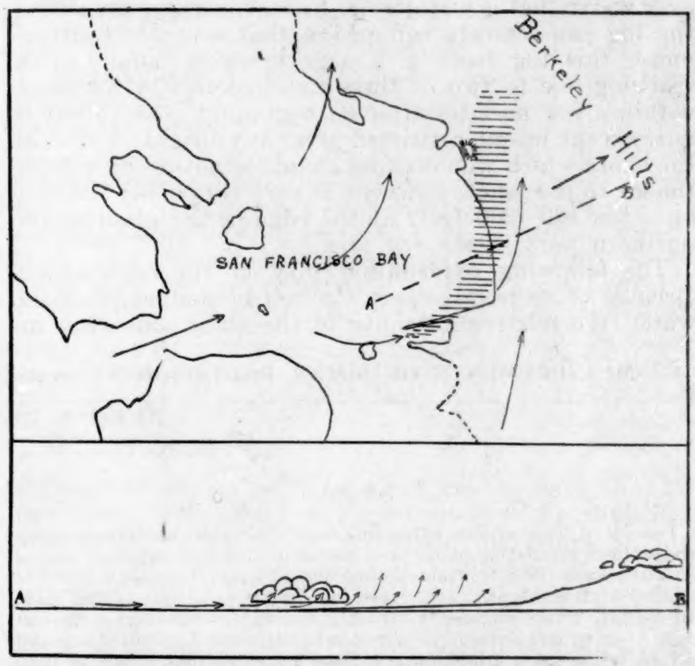

FIG. 1.—Map and cross section illustrating occurrence of fog bank over eastern side of San Francisco Bay and adjacent land. Shaded portion=approximate area of fog; arrow show estimated drift of air currents, from observations of fog and smoke. Vertical scale of section along line AB greatly exaggerated.

[1] This is, technically speaking, a band of strato-cumulus cloud, since it is not in contact with the ground. Such low cloud, forming over the plain and the Berkley Hills to the east, is locally known as "high fog," though it frequently hovers but a few yards from the ground.

An interesting detail concerning the well-known and much-described sea fogs of San Francisco Bay came again to the writer's attention not long since. The relations of land and water as they affect the behavior of the fog west of the bay are easily understood from the map herewith. Under the impetus of the prevailing west-southwest wind, when conditions outside on the Pacific Ocean are favorable, the fog often flows over the two peninsulas (accounting thereby for the proverbial chilliness of the San Francisco summer) and streams through the Golden Gate. Seen from the campus of the University of California, its spreading front entering the bay looks not unlike the front of a distant glacier. Quite commonly this front is for some hours kept "burned off" over the inner shores of the peninsulas and the relatively warm waters of the bay, leaving the broad expanse of water and the adjacent plain at the foot of the Berkeley Hills clear and sunny. But occasionally the following variant on these conditions occur, the major part of the bay and plain still remaining clear.

Beginning somewhere near Goat Island and extending northward toward the shore, a fog bank forms, of considerable density though never equaling that of the thick ocean fog. Its south end is almost always wispy and ragged, and its north end usually trails off in the wind up the plain to the northern part of the Berkeley Hills. There is clear air west of it over the bay, and clear air east of it over the sloping plain.

The conditions at first thought seem all against the formation of fog in that particular zone. The fog-laden sea air in its passage over the relatively warm waters of the bay is warmed enough for the fog in it to evaporate. The fog reforms, however, over the eastern part of the bay, in spite of the fact that the water is very shallow, and hence on sunny days is warmer than the deeper water on the west. There can be little, if any, chilling of the already cool incoming air as it crosses this belt of warmish water. It is not likely that the conditions of cold air over water that is warmer are here even approximated—the fog can scarcely come from that source. Furthermore, this fog bank is a quick-growing affair, often reaching one to two or three hundred feet in thickness within a few minutes after its beginning. And there is not, except in one restricted area, any height of land at the shore which would cause cloud formation by forcing the air to rise; such, however, is very commonly the case on a low hill (300 feet) at the edge of the plain in the northern part of the fog area.

The following explanation may be the correct one. Because of its passage over the belt of shallow, warmish water, the relative humidity of the air is somewhat increased as compared to the relative humidity over the cooler water of the bay. Therefore, only a very slight further cooling may be necessary to cause condensation. But a run over the land would have the opposite effect of reducing the relative humidity. Now, over the plain on sunny days convection currents are active, and they may be strong enough to function as a sort of buffer against and over which the cooler and moister air is forced to rise, the convection currents being at the same time weak and dry enough to cause of themselves little or no cloud formation. Condensation would take place then only on the western edge of the convection area, where the slight lifting of the cool and very humid air causes the necessary further reduction in temperature. The level of condensation is only a few yards above the house tops. Usually the air over the plain is clear, though occasionally the convection currents do form small rags of cloud drifting toward the hills on their way to merge with the major cloud mass about the summits.

In correspondence with the writer, Dr. C. F. Brooks suggests a possible additional cause for the condensation observed, namely, that the somewhat warmer air along the shore belt of shallow water, moving relatively slowly because of friction with the shore, is chilled to the condensation point by the admixture of faster-moving air from the west. This cause may well operate in conjunction with the convection barrier to produce the effect. As may be seen from the sketch, the more northerly part of the fog belt, trailing off over the land, is in a position favorable to such action. But the beginning point of the belt is somewhat offshore, and hence presumably not under the influence of this land-induced friction. The following is offered as a possible explanation of the condensation here. The convection barrier plus friction and mixture may cause a flattened wedge-shape mass of slightly slower-moving air to extend out some distance from the land, and so, to act as a sort of inclined plane up which the oncoming air from the west would move. The result would be convection cooling and mixture cooling combined, with the fog as a consequence.

As is commonly the case, on the last occasion when this fog bank formed it persisted until late afternoon, the air over the bay remaining clear and that over the plain for the most part clear. With the gradual weakening of convection the buffer effect here suggested gave way and the local fog bank disappeared. No longer forced to rise by the convection currents, and mixing instead with the warmer air over the plain, the moisture which had before been visible as fog now remained as vapor, until its rise over the higher summits of the hills again caused condensation.

MEASUREMENTS OF SOLAR RADIATION AT MADISON, WIS., WITH THE CALLENDAR PYRHELIOMETER.

By ERIC R. MILLER, Meteorologist.

(Weather Bureau Office, Madison, Wis., Apr. 13, 1920.)

SYNOPSIS.

Results of observations extending over nine years are summarized, and data of related phenomena of duration of bright sunshine and of cloudiness are given. A midsummer depression in the annual march of midday normal intensity is ascribed to a maximum of haze at that time, due in turn to the increased evaporation of water and stronger convection. Spring and autumn depressions in the annual march of sun and sky radiation upon a horizontal surface are explained as arising from the double maximum in the annual march of frequency of "Colorado lows." The suggestion is offered that this double maximum is produced by the most efficient cooperation at intermediate seasons of the stationary barometric depression in Northern Mexico and the eastward drift of the atmosphere, the annual oscillations of which are in opposite phases.

Introduction.—A continuous record of the intensity of the radiation from the sun and sky upon a horizontal surface has been kept automatically at Madison, Wis., since the beginning of April, 1911. Nine years' record is now available for study. Discussions of shorter periods have previously been published, and are listed at the end, (**1**), (**2**).

Instruments.—Callendar bolometric sunshine receiver No. 9864 has been used throughout the series of observations. This is the four-grid type, already described and illustrated by Kimball (**3**). Two different recorders have been used, Callendar Recorder No. 143 was used from

April 3, 1911, to July 17, 1912, Recorder No. 322 from that date to the present time.

Exposure.—The receiver is exposed on top of the thermometer shelter of the United States Weather Bureau Office, on North Hall, University of Wisconsin, a building on the upper campus, on a hill rising abruptly from the south shore of Lake Mendota. Its altitude is 1,009 feet, or 308 meters, above sea-level, 163 feet above the surface of Lake Mendota, 71 feet above the ground, and 12 feet above the roof. The horizon of the instrument is free except to the southwest, where the low, pyramidal roof of University Hall rises to a point 4°, and the chimney of the university heating plant farther on, 5° above the horizon. The dome of University Hall, which burned on the morning of October 10, 1916, rose to 11°, and a flagstaff on the dome to 15°, between S. 61° W. and S. 67° W. The sun passed behind the dome each afternoon from January 18 to February 21, and from October 21 to November 25 each year. The maximum effect of this artificial eclipse of the sun is estimated to have been a loss of less than a small calorie a day on clear days. The atmosphere of Madison is generally free from dense smoke, since the city has few manufacturing plants, and these are all 2 or 3 miles east of the station. In winter there is often light smoke from domestic heating and cooking, and occasionally in very cold weather smoke or condensed steam from the university heating plant and from locomotives passes over the sun, especially when the wind is southwest. The oriention of the receiver, which has an important effect on its indications, is with the black grids in the meridian, north and south, while the bright, compensating grids lie east and west.

Reduction factor.—Prof. Callendar supplied with the instrument a factor of 0.0552 gram-calorie per square centimeter of exposed surface, per minute, per scale division of 4.0 mm. on the paper supplied by the makers. Paper ruled in inches and tenths has been used with register No. 322, and for this the equivalent factor is 1 inch to 0.3505 calories, etc. The time-scale of this recorder has been changed to make it more open, a scale of 0.797 inch to the hour being used. The instrumental factor has been utilized in ruling scales on brass (1) to read calories per minute, divided to hundredths of calories, each division being 0.725 mm., and (2) to read calories per hour, divided to calories, each division 1.208 calories. These scales enable the sheets to be read off very rapidly.

Instrumental errors.—Although the Callendar pyrheliometer is an invaluable aid to the meteorologist, the full realization of its purpose is frustrated by a variety of physical conditions, some of which can probably not be overcome. Five or six of these sources of instrumental error are discussed in an accompanying paper on the "Characteristics of the Callendar pyrheliometer."[1] The data given in the present paper have not been corrected for error, partly in order that the results may be compared with similar observations elsewhere and partly because the total error is unknown under some circumstances.

Results of registration.—The sums and means of sun and sky radiation upon a horizontal surface are tabulated by hours, days, months, and years, and represented in curves at the end of this paper. The most

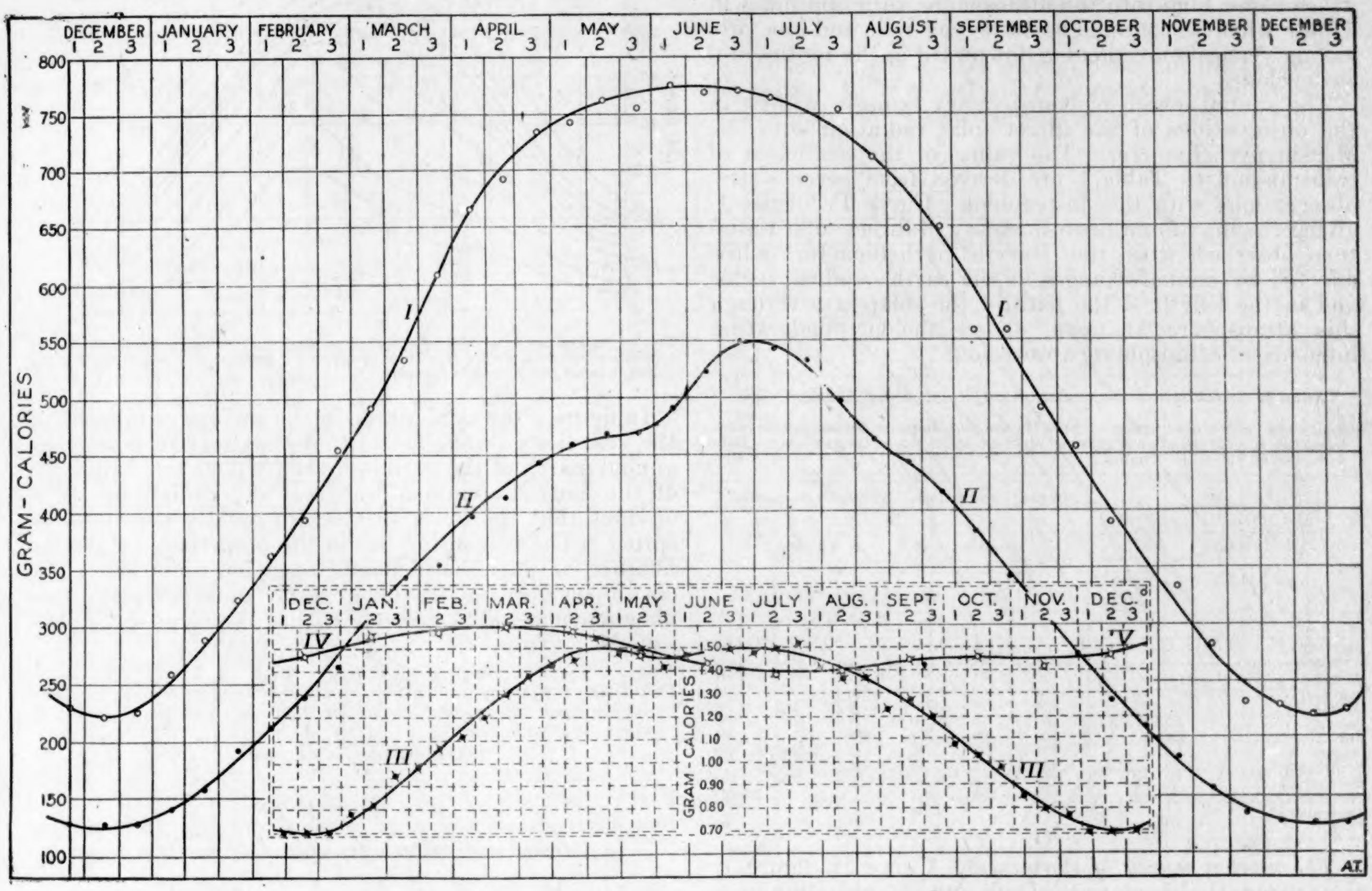

FIG. 1.—Average and maximum intensities of radiation at Madison, Wis.

[1] This REVIEW, pp. 344-347.

important factors in causing variation of these data are, naturally, the daily and annual changes in the relation of the earth to the sun by rotation on its axis and revolution in its orbit. Superimposed upon these normal variations of "solar climate" are all the irregularities of the weather. Of these, two phenomena deserve especial attention, namely, the annual march of atmospheric transparency and the annual march of storminess.

Annual march of transparency.—The transparency of the atmosphere is reduced by haze and by water vapor. Haze may be regarded as caused by solid particles, as dust and smoke, and liquid droplets of water, which can exist at much less than the saturation vapor pressure for a plane surface of water. Aside from large accidental variations of the dust content following volcanic eruptions, there is a fairly regular annual march ranging from a maximum in summer, when the soil is dry and dusty and there is active convection to carry dust and water vapor high into the atmosphere, to a minimum in winter when the ground is snow covered, and the prevailing vertical movement is downward in the continental anticyclone.

The annual march of transparency is most evident in the observations of the direct solar radiation with the Marvin pyrheliometer. The values of the coefficient of transmission in Table 1 are derived from seven years' observations with this instrument. Curve IV, figure 1, giving the maximum noon intensity of direct solar radiation observed with the Marvin pyrheliometer, while affected by annual changes in the earth's radius vector and in the length of the path of the solar rays through this atmosphere at noon, shows the preponderating influence of atmospheric absorption.

TABLE 1.—*Atmospheric transmission coefficient, a, for Madison, Wis.*

[From seven years of observation with the Marvin pyrheliometer, by comparison of the intensities of solar radiation at different altitudes of the sun on the same day. Data furnished by Dr. H. H. Kimball.]

Month.	Morning observations.			Afternoon observations.		
	Air mass.			Air mass.		
	1.5	2.0	2.5	1.5	2.0	2.5
January	....	0.824	0.859	....	....	0.849
February	0.841	.837	.849	....	0.843	.852
March	.820	.831	.844	0.812	.837	.847
April	.784	.800	.811	.766	.800	.811
May	.744	.751	.761	.744	.726	.738
June	.750	.776	.795	.714	.754	.767
July	.700	.733	.751	.698	.711	.731
August	.734	.759	.781	.713	.730	.736
September	.752	.771	.783	.740	.757	.773
October	.739	.768	.792	....	.771	.795
November	....	.820	.824	....	....	.837
December	....	....	.836	....	....	....

The annual march of storminess.—Curve II, figure 1, the average daily amounts of sun and sky radiation on a horizontal surface, shows a marked depression in April, May, and June, and another lesser depression in August and September. These depressions occur before and after the time of lowest transmission coefficient, and are therefore not due to atmospheric haze. It will be noted that these depressions do not appear in curve I, figure 1, the maximum recorded sums of daily radiation from sun and sky on a horizontal surface as they would if due to variations in transparency. That the spring and autumn depressions are due to a larger proportion of cloudy days is clearly shown by the frequency distribution of the daily sums of radiation.

For illustration use is here made of the "method of percentiles" which is explained by Yule, Theory of Statistics, page 150, in the following words:

If the values of the variable be ranged in order of magnitude and a value P of the variable be determined such that a percentage p of the total frequency lies below it and $100-p$ above, then P is termed a percentile. The deciles, or values of the variable which divide the frequency into 10 equal parts form a natural and convenient series of percentiles to use.

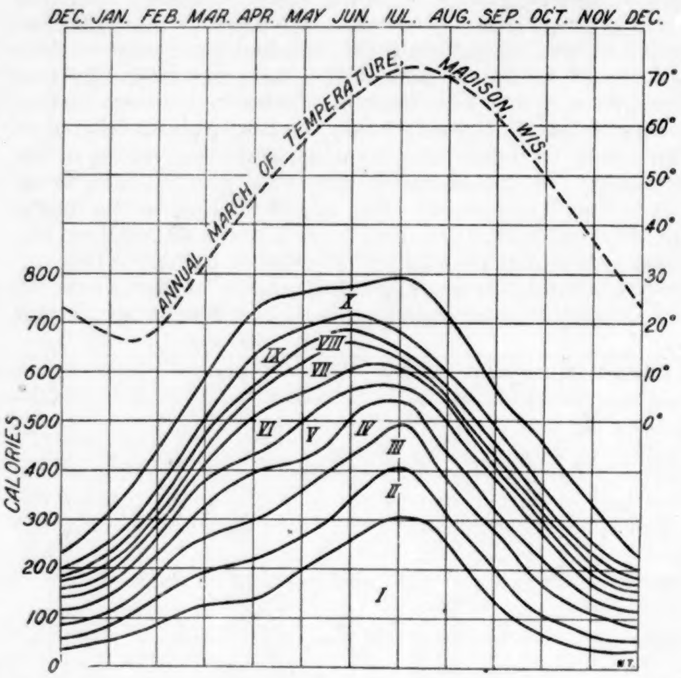

FIG. 2.—Annual march of the deciles of the frequency distribution of daily sun and sky radiation, showing greater cloudiness in spring by occurrence of large proportion of days in lower part of scale of intensity.

In figure 2 the same decile in the successive months of the year lies on one line, so that the diagram shows the annual march of the deciles of the frequency distribution of the daily amounts of sun and sky radiation. It is obvious that the lower deciles are greatly depressed in spring. The reason for this is the occurrence of a large number of days with small totals of radiation. The customary form of frequency table does not show this phenomenon, but it does show that the clear day is the "mode." (Table 2).

TABLE 2.—*Frequency distribution of daily sums of radiation from sun and sky upon a horizontal surface, at Madison, Wis., April, 1911, to March, 1919, inc.*

[The principal mode in italics.]

Range of calories.	Percentage of days.											
	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
751–800	......	......	......	......	1	......	......	......	......	......	......	......
701–750	......	......	......	1	6	3	4	......	......	......	......	......
651–700	......	......	......	4	*13*	12	12	1	......	......	......	......
601–650	......	......	......	10	12	*17*	*25*	5	......	......	......	......
551–600	......	......	3	*15*	8	9	17	18	2	......	......	......
501–550	......	......	8	12	10	12	11	*23*	5	......	......	......
451–500	......	......	17	6	4	10	7	9	14	......	......	......
401–450	......	2	*12*	10	9	5	6	9	*23*	1	......	......
351–400	......	13	11	5	8	6	6	9	13	14	......	......
301–350	......	19	8	6	5	5	3	6	10	*20*	......	......
251–300	13	*25*	7	7	3	8	4	8	7	19	13	......
201–250	*23*	8	8	6	6	4	1	4	6	8	*23*	12
151–200	21	12	7	7	6	3	2	4	6	8	22	*33*
101–150	19	9	7	6	4	5	1	2	7	11	14	19
51–100	15	6	5	3	2	1	1	2	6	12	15	17
1–50	9	5	2	2	1	......	......	......	......	6	12	19

The cause of the spring and autumn depressions in the annual march of radiation appears to be a double maximum in the annual march of storminess in the region of Madison. The annual march of storminess for each 5°

zone from latitude 25 to latitude 55°, between longitudes 85° and 90°, is shown in Table 3, which are derived from data in the monograph of Bowie and Weightman (**4**).

Table 3.—*Number of* lows *that crossed longs. 85°–90° in the 21 years, 1892–1912.*

[Maxima in italics.]

Lat. zone.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
25–30	*16*	*16*	4	4	1	2	2	3	9	5	5	13
30–35	30	*34*	22	17	13	6	3	8	10	9	25	30
35–40	28	*41*	32	25	15	17	6	10	9	5	29	40
40–45 [1]	35	37	34	*50*	*50*	27	33	30	27	24	*51*	39
45–50	57	40	36	48	47	48	64	*68*	60	63	62	58
50–55 [2]	8	7	7	......	2	3	15	6	11	10	6	5

[1] Madison in this zone, Lat. 43° 05′. [2] Data incomplete.

Madison appears to lie in a transition zone between the northern border with its summer maximum of storminess and the southern and central States with their winter maximum. This phenomenon is less probably a shifting of the storm belts than an annual change in the tendency of different areas to form storms. While the continent cools in winter the Gulf of Mexico remains warm, and thereby comes to be a source of cyclonic storms at that season. A frequent type of storm experienced in Wisconsin is that from the southwest, designated by Bowie and Weightman the "Colorado low." The Colorado low is the only group of storms in their Table 1 having a double maximum of frequency in spring and fall.

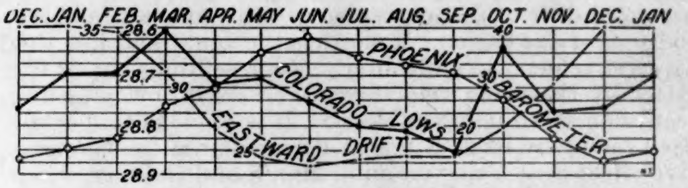

Fig. 3.—Annual march of frequency of Colorado lows, of atmospheric pressure at Phœnix, Ariz. (inverted), and of mean velocities of centers of low pressure, showing maxima of Colorado lows in spring and autumn, when the Mexican center of low pressure, and the westerly drift of the atmosphere most effectively cooperate to produce moving storms.

The cause of the double annual period of the Colorado low appears to be the effective cooperation in spring and autumn only of two storm-producing factors that fluc-

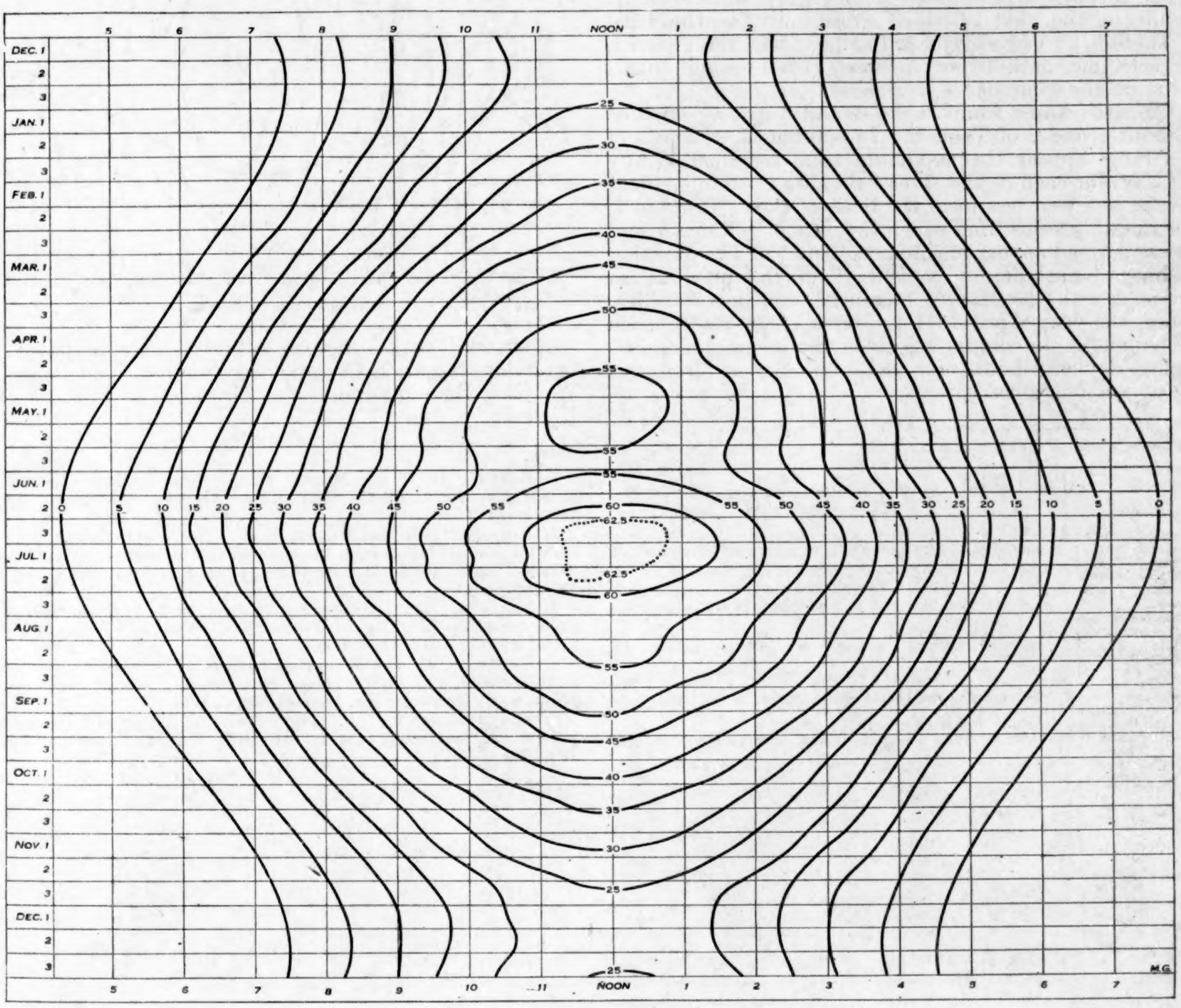

Fig. 4.—Pyrhelisopleth, for Madison, Wis.

tuate annually in opposite phases. These are the low-pressure area of the southwestern United States and northern Mexico and the speed of the prevailing westerlies over the United States. The tendency of the "Mexican center of action" to form a storm is greatest when the pressure is lowest. This "cyclonicity" is represented in figure 3 by inverting the annual march of atmospheric pressure at Phoeniz, Ariz. The force required to move a cyclone from Arizona eastward must be supplied by the eastward drift of the atmosphere. This extends farthest south over the region, "following the sun," and has the greatest velocity in midwinter. Representing (Fig. 3) the latter by the mean velocities of centers of low pressure, from von Herrmann's tables (**5**), it is obvious that while each factor by itself is not at its maximum the cooperative effect is at a maximum in March and October, when the maxima appear in the curve of annual march of "Colorado LOWS."[1]

Construction of the tables of data.—The arithmetical mean of the hourly and daily sun and sky radiation for each month is the basis of Table 4. A similar table, but for each "decade" (1–10, 11–20, and 21-end) of each month forms the basis of figure 4. Table 4 includes one year more of reservations than figure 4.

The mean hourly total for hours when there were no clouds in the sky, obtained graphically, is the basis of Table 5. Clear sky for a full hour was the criterion for selecting data to be included, even though other hours on the same day were cloudy.

The daily sums from Tables 4 and 5 are repeated in columns 1 and 2 of Table 6. In columns 3, 4, and 5 of this table appear the maximum total recorded in any one day, for each of the three "decades." Similar data but for one year less form the basis of Curve I, figure 1. The monthly sums from which the data of columns 1 and 2 were derived appear in columns 6 and 7. The duration of bright sunshine, in percentage of the possible, as recorded with the Marvin mercurial sunshine recorder, during the years April, 1911 to March, 1920, inc., appear in column 8. In column 9 is given the mean cloudiness, during daylight hours, for the same period, from bi-hourly personal observations.

[1] Figure 3 is based on the following data:

	Jan.	Feb.	Mar.	Apr.	May.	June	July.	Aug.	Sept.	Oct.	Nov.	Dec.
A. Mean barometer Phoenix, Ariz....	28.849	0.819	0.756	0.720	0.646	0.617	0.663	0.674	0.684	0.744	0.820	0.869
B. Mean velocity of centers of low pressure, 1878–1904..............	34.8	34.8	31.6	26.9	24.3	24.0	24.4	24.6	24.8	27.4	30.7	34.9
C. Number of Colorado LOWS, 1892–1912..............	30	31	39	28	30	25	19	20	14	36	23	23

A=Bigelow, F. H. Barometry of the United States, Report of the Chief of the Weather Bureau, 1900-01, vol. 2, p. 557.
B=von Herrmann, MONTHLY WEATHER REVIEW, 35, 169–171.
C=Bowie and Weightman, MONTHLY WEATHER REVIEW, SUPPLEMENT No. 1, 1914. Table 1.

The radiation-history of Madison for nine years is given in Table 7, where the monthly and annual totals of radiation in gram calories appear month by month and year by year for the entire period. In order to show the excesses and deficiencies the percentage of each month in terms of the nine-year mean has been calculated. The most noteworthy features of this table are the long-continued deficiency in the summer of 1915, which was also extraordinarily wet and cold, and the much greater variability of the data for the months November to February than for the rest of the year.

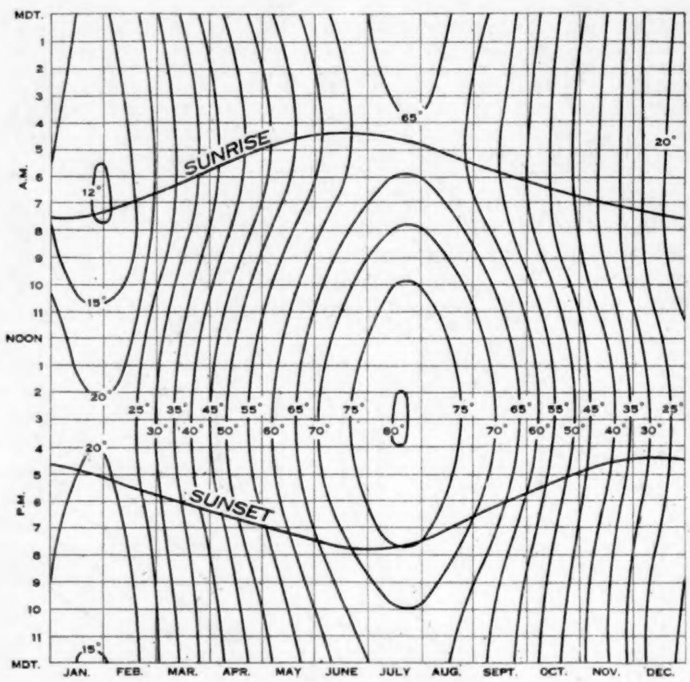

FIG. 5.—Thermisopleth, for Madison, Wis.

Acknowledgment.—Figures 1 and 4 were prepared in the Solar Radiation Investigation Section, United States Weather Bureau, under the direction of Prof. H. H. Kimball.

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TABLE 4.—*Mean hourly, and daily intensity, of the vertical component of sun and sky radiation, at Madison, Wis., gram calories. Apr., 1911, to Mar., 1920, inc.*

Month.	For the hour, apparent solar time, ending at—																Daily.
	5	6	7	8	9	10	11	Noon.	1	2	3	4	5	6	7	8	
January				1.5	8.5	17.2	24.6	28.8	29.1	25.1	17.8	8.8	2.0				163.3
February			0.2	5.3	15.1	25.5	33.7	38.6	39.0	35.3	27.7	16.9	6.0	0.5			243.9
March			3.0	12.6	25.2	36.3	43.7	48.0	48.4	44.2	37.1	25.8	13.6	3.9	0.0		342.0
April		1.3	8.4	20.2	32.0	41.3	48.8	52.2	52.2	48.0	40.5	30.3	19.0	8.4	1.6		404.4
May	0.2	4.6	14.6	26.0	37.0	46.2	52.9	55.9	55.2	51.7	44.5	35.6	24.8	13.4	4.5	0.2	467.4
June	0.9	7.4	18.6	30.2	40.5	48.8	55.3	59.2	59.7	55.6	49.7	40.3	29.3	16.7	6.4	1.0	519.6
July	0.4	5.9	17.0	29.5	41.7	51.0	58.2	62.3	61.0	58.0	51.0	41.3	29.4	16.5	5.9	0.6	529.4
August		2.1	10.6	22.7	33.9	43.9	51.8	56.6	56.2	52.0	45.6	36.0	23.7	11.1	2.8		448.9
September		0.2	5.0	15.4	26.6	36.2	43.5	47.7	46.1	41.8	35.4	25.3	13.7	4.2	0.3		341.4
October			0.7	6.6	16.0	25.2	32.3	35.5	34.9	31.3	25.2	16.0	6.2	0.8			230.7
November				2.0	8.9	16.9	23.5	27.4	27.5	23.7	17.3	9.2	2.4				158.8
December				0.5	5.8	13.7	19.7	23.1	23.3	20.1	13.9	6.3	1.2				127.8

TABLE 5.—*Average hourly and daily intensity of the vertical component of radiation from sun and sky under cloudless skies; gram calories.*

Month.	For the hour, apparent solar time, ending at—																Daily.
	5	6	7	8	9	10	11	Noon.	1	2	3	4	5	6	7	8	
January				3.0	17.1	28.7	40.3	47.3	47.3	39.1	30.0	15.6	3.9				272.3
February			1.0	10.4	27.9	42.2	55.2	62.3	60.4	54.2	44.4	28.2	11.6	2.1			400.1
March		1.0	6.5	23.3	42.0	57.0	67.4	75.1	74.3	67.5	58.4	42.1	23.6	7.6			545.7
April		2.1	13.8	31.7	51.0	64.8	73.5	80.9	79.9	72.9	63.9	48.1	30.4	12.8	2.3		628.0
May	1.0	8.9	26.2	43.3	59.0	71.0	78.0	83.3	83.0	77.0	68.9	54.0	38.5	22.2	8.5	1.0	723.6
June	1.5	10.5	27.8	44.6	58.7	71.7	77.7	82.0	82.0	77.7	69.0	55.0	39.7	23.4	9.7	1.7	732.7
July	.5	5.6	20.5	36.5	53.0	65.7	72.6	78.0	77.3	71.8	64.2	51.5	35.1	18.3	6.0	0.9	657.6
August		2.0	12.4	28.0	43.9	58.8	66.3	71.8	69.6	64.0	55.5	42.2	24.5	10.4	2.0		551.5
September		.7	6.2	20.8	37.1	51.3	60.9	65.3	63.0	58.2	48.3	35.2	17.4	5.2	0.7		470.3
October			.2	6.7	20.5	33.4	44.3	48.7	48.8	43.3	33.3	20.2	5.6	.2			305.2
November				2.9	13.1	26.1	36.8	41.6	40.9	35.6	26.2	13.5	3.3				240.4
December				1.5	9.1	20.6	31.3	34.9	35.2	29.4	20.4	8.8	2.0				193.1

TABLE 6.—*Summary of means and extremes of radiation, etc., by months.*

Month.	Mean daily.		Greatest recorded daily radiation.									Monthly amounts.		Duration of sunshine.	Mean cloudiness, daylight hours.
			1''-10''			11''-20''			21''-end.						
	All days.	Clear days.	Amount.	Date.	Year.	Amount.	Date.	Year.	Amount.	Date.	Year.	All days.	Clear days.		
														Per cent.	Per cent.
January	163.3	273.3	259	9	1912	289	19	1912	323	31	1918	5,063	7,496	45	66
February	243.9	400.1	363	9	1912	394	20	1917	455	29	1912	6,905	10,258	52	64
March	342.0	545.7	503	7	1920	534	20	1918	609	28	1912	10,602	15,365	57	63
April	404.4	628.0	666	7	1911	692	20	1911	734	24	1911	12,131	18,840	54	65
May	467.4	723.6	743	3	1911	762	11	1916	755	30	1915	14,489	21,950	58	63
June	519.6	732.7	765	9	1913	769	16	1917	770	28	1911	15,591	21,982	63	61
July	529.4	657.6	764	2	1917	780	12	1911	788	21	1911	16,415	21,227	71	50
August	448.9	551.5	711	1	1913	648	13	1916	649	29	1911	13,917	18,210	64	51
September	341.4	470.3	557	1	1915	559	19	1911	490	21	1915	10,242	14,110	56	57
October	230.7	305.2	456	2	1913	390	11	1914	327	27	1914	7,195	10,704	48	61
November	158.8	240.0	334	2	1911	283	14	1916	232	22	1914	4,752	7,190	41	65
December	127.8	193.1	230	3	1911	225	15	1919	225	30	1914	3,944	5,986	38	67

TABLE 7.—*Monthly and annual sums, and percentages of the 9-year mean, of the sun and sky radiation upon a horizontal surface at Madison, Wis., from April, 1911, to March, 1920, inclusive, in gram calories per square centimeter per minute.*

Year.		Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
1911	Calories				11,472	15,843	16,153	17,202	14,072	10,598	6,533	4,554	4,217	123,214
	Per cent				95	109	104	105	101	104	91	96	107	102
1912	Calories	6,297	6,953	12,006	12,663	11,948	16,891	15,623	13,380	10,001	7,932	5,137	4,024	122,855
	Per cent	124	101	113	104	83	108	95	96	98	110	108	102	101
1913	Calories	4,651	7,584	10,008	13,380	13,906	17,704	17,413	13,028	9,829	7,380	4,218	3,717	122,818
	Per cent	92	110	94	110	96	114	106	93	96	103	89	94	101
1914	Calories	3,196	7,422	9,854	12,213	16,238	15,193	17,417	14,128	11,060	7,070	5,656	4,320	123,767
	Per cent	63	107	93	101	112	97	106	102	108	98	119	110	102
1915	Calories	4,988	5,062	11,883	13,069	12,494	14,605	13,273	12,884	9,429	7,934	4,947	3,519	114,087
	Per cent	99	73	112	108	86	92	81	93	92	110	104	89	94
1916	Calories	4,117	7,292	10,272	12,727	15,024	15,673	17,872	14,516	10,486	7,793	4,831	4,469	125,072
	Per cent	81	106	97	105	104	101	109	104	102	108	102	113	103
1917	Calories	6,106	8,147	10,031	11,730	16,002	13,630	16,736	14,239	10,562	6,400	4,319	4,190	122,092
	Per cent	120	118	95	97	110	87	102	102	103	89	91	106	101
1918	Calories	5,982	7,145	11,446	11,883	14,194	15,681	16,187	13,711	10,246	7,026	4,395	2,697	120,593
	Per cent	118	103	108	98	98	101	99	99	100	98	92	68	99
1919	Calories	4,878	5,926	9,739	10,042	14,752	14,779	16,014	15,297	9,970	6,298	4,810	4,342	116,847
	Per cent	96	86	92	83	102	93	98	110	97	88	101	110	96
1920	Calories	5,357	6,616	10,175										
	Per cent	106	96	96										
Mean		5,063	6,905	10,602	12,131	14,489	15,591	16,415	13,917	10,242	7,195	4,752	3,944	121,246

SOME CHARACTERISTICS OF THE CALLENDAR PYRHELIOMETER.

By ERIC R. MILLER, Meteorologist.

[U. S. Weather Bureau, Madison, Wisconsin, Apr. 13, 1920.]

SYNOPSIS.

Theory of the Callendar automatic pyrheliometer. The indications of the Callendar pyrheliometer differ from the calculated intensities of radiation upon a horizontal surface on account of (1) greater sensitiveness for low intensity than for high; (2) selective absorption of short-wave radiation by platinum compensating grids; (3) internal reflection of light from glass cover to grids; (4) selective absorption by cover glass of ultra-violet and infra-red radiation from sun, and total absorption of radiation from grids; (5) grid surfaces not geometrical planes; (6) lag of registration behind radiation.

The data in the accompanying paper [1] on "Measurements of Solar Radiation at Madison, Wis., with the Callendar pyrheliometer" are entirely uncorrected for instrumental error. While such data may be used for comparison with data obtained with the same type of instrument elsewhere, it is obviously desirable to know the probable relation of the data to absolute heat units. Study of the apparatus has also suggested the possibility of eliminating two of the most obnoxious errors.

The "bolometric sunshine receiver" of Prof. H. L. Callendar, the eminent English physicist, is related structurally to both the bolometer and the electrical resistance thermometer. Its electrical circuits are those of the four-lead compensated electrical resistance thermometer, but with the compensating leads extended to include compensating grids of the same dimensions as the thermometer grids. The thermometer grids are blackened with enamel, the compensating grids are bare, bright, platinum wire. The receiver at Madison, like that described by Kimball (**1**) has four square grids—two black thermometer grids, two bright compensating grids—arranged checkerboard fashion in a horizontal plane, and inclosed in a vacuum bulb of glass.

This apparatus is intended to record continuously, with the aid of a Callendar Recorder, Wheatstone Bridge Type, the intensity of the radiation from the sun and sky as it would be received upon a horizontal surface. This datum, the vertical component of sun and sky radiation, is of fundamental importance in all large-scale climatological studies, where the local irregularities of the surface become negligible, and the total amount of energy delivered to the earth's surface is required.

The comparison instruments used at Madison in testing the Callendar apparatus are the Marvin pyrheliometer and the Smithsonian pyranometer, the former from the beginning of observations in 1911, the latter from 1917. The Marvin pyrheliometer, which has been described by Kimball (**2**) and Foote (**3**), measures only the intensity of direct solar radiation at normal incidence. The Callendar pyrheliometer is compared with that of Marvin by shading the Callendar receiver from the direct rays of the sun with the Kimball screen (**1**, p. 477), measuring the drop in the ordinate on the recorder thereby produced, and dividing this by the sine of the sun's altitude. The Smithsonian pyranometer, described by Abbot and Aldrich (**4**) measures the same component of sun and sky radiation as the Callendar apparatus, and is supplied with attachments to adapt it to measure the sun's radiation alone, or the sky radiation alone. It can therefore be compared with the Marvin pyrheliometer, and with the residual ordinate of the Callendar pyrheliometer when shaded from the sun.

[1] This REVIEW, pp. 338-343.

Although the Marvin pyrheliometer has been established as a primary pyrheliometer by the experiments of Marvin, Kimball, and Foote, it is used at Madison as a secondary pyrheliometer based on the Smithsonian Standard, and has been intercompared at approximately biennial intervals. The pyranometer is also based upon the Smithsonian Standard, but pyranometer No. 1 at Madison has given indications slightly below those of the Marvin pyrheliometer, and shows a progressive change of ratio with increasing altitude of the sun, ranging from 91 per cent of the Marvin at 20° to 99 per cent at 60°. Pyranometer No. 2 at Washington shows a similar change of ratio, but its indications are higher. The difference is not due to the ammeters[1] used with the two instruments. The two pyranometers were carefully intercompared during their standardization at the Smithsonian Institution.

The factor for receiver No. 9864, at Madison, supplied by Prof. Callendar is equivalent to 0.3505 gram calories per square centimeter of horizontal surface per minute, for each inch of ordinate on the trace sheet. This factor was determined by Prof. Callendar by comparisons with an Ångström pyrheliometer. The Ångström standard gives results 3.23 per cent below the Smithsonian Standard (**5**) and other Callendar instruments have had to have their constants increased by this much or more to agree with the Smithsonian standard, but No. 9864 gives results agreeing on the average very closely with the Smithsonian Standard for solar altitudes above 20° without such a correction. The instrumental characteristics of the Callendar pyrheliometer will now be systematically discussed.

SCALE ERROR.

The Callendar pyrheliometer depends upon the static method of pyrheliometry, (**6**) in which is determined the maximum excess of temperature over that of the surrounding medium that is attained by a body exposed to solar radiation. Inasmuch as the radiation and the rate of loss by conduction and radiation enter the equation exponentially, it is not to be expected that the relation will be linear, as is assumed by the employment of a uniform reduction factor. The temperature attained by the black grid under intense radiation will not be as high in proportion to the radiation as under less intense radiation.

Experimenting with a rotating disk diaphragm, Kimball (**1**, p. 475, Table 3) found that the sensitiveness of the Callendar pyrheliometer compared with the Marvin pyrheliometer by pointing both directly at the sun decreases with increasing intensity of radiation in the following proportion:

TABLE 1.

Intensity of radiation.	10 per cent.	20 per cent.	30 per cent.	50 per cent.	100 per cent.
Ratio (Callendar/Marvin)	1.18	1.13	1.10	1.05	1.00

The Callendar receiver at Madison was not subjected to this experiment, but the phenomenon, partly offset by other errors, clearly appears in the following table based on comparisons, under working conditions, with the pyranometer.

[1] The mil-ammeter employed at Washington has had its scale errors determined at the Bureau of Standards, and its corrected readings can not be in error by more than ±1 per cent; that at Madison has been compared with precise instruments in the University of Wisconsin with a similar result.

TABLE 2.

	No. of observations.	Mean radiation (cal.)	Callendar constant (cal./in.).	Radiation intensity, per cent of:					Sensitiveness, per cent of:				
				A.	B.	C.	D.	E.	A.	B.	C.	D.	E.
A	25	1.334	.359	....	....	....	....	....	....	....	....	....	....
B	38	.918	.352	69	....	....	....	....	102 (102)	....	....	....	....
C	82	.879	.351	66	96	....	....	....	102 (103)	100 (100)	....	....	....
D	21	.516	.342	39	56	59	....	....	105 (107)	103 (104)	103 (103)	....	....
E	36	.362	.355	27	39	41	75	....	107 (111)	105 (107)	105 (107)	102 (102)	....
F	39	.153	.333	13	17	17	32	51	108 (117)	106 (114)	105 (114)	103 (109)	101 (105)

A = Radiation from sun and sky, midsummer, within 2½ hours of noon.
B = Sun alone, all altitudes of sun included.
C = Sun and sky, all altitudes of sun.
D = Sun and sky, autumn, within 2½ hours of noon.
E = Overcast skies.
F = Sky alone, clear blue skies.
Calculated sensitiveness, in parentheses, from Table 1.

PLATINUM SELECTIVE ABSORPTION ERROR.

Researches on the reflecting power of metals by Rubens and Hagen (**7**) and by Coblentz (**8**) have shown that all metals vary in their reflecting power for different wave lengths of the spectrum, tending to reflect less and absorb more at short wave lengths than at long. Platinum, which reflects 70 to 80 per cent of the energy in wave lengths of .8μ to 1.5μ, absorbs 50 to 66 per cent of the energy between .25μ and .40μ. The latter region of the spectrum of sunlight is not only the region of greatest intensity, but also the region of greatest change of intensity from high sun to low; furthermore, it is the

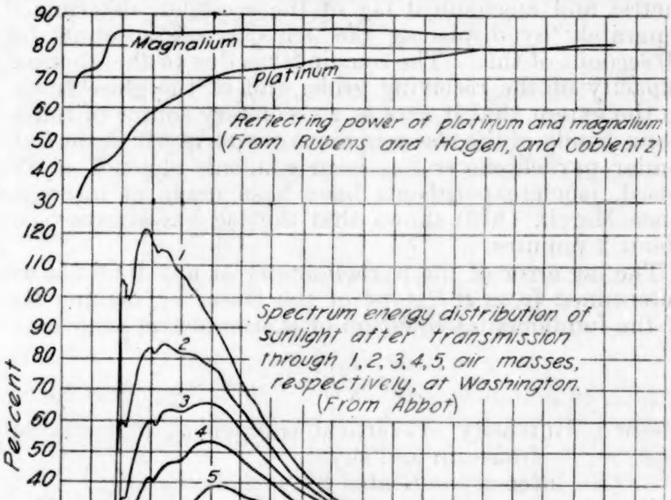

FIG. 1.—Spectrum energy curves for high and low sun, and for blue sky light at dawn and midday, and the reflecting power of platinum.

region of greatest intensity in the spectrum of sky light. Curves representing the reflecting power of platinum throughout the spectrum, as determined by Rubens, Hagen, and Coblentz, the distribution of energy in the solar spectrum for high and low sun, according to Abbot (**9**) and the spectrum of sky light at dawn and midday, according to Nichols (**10**) appear in figure 1. Figure 2, drawn to the same scale, shows the proportion absorbed by platinum when exposed to these several types of spectral distribution. Graphical integration indicates that platinum absorbs 30 per cent of the light from a high sun (30° or higher, air mass not greater than 2) and 26 per cent of the light from low sun (10° or less, air mass equals or exceeds 6). Of sky radiation about 45 per cent is absorbed at both dawn and midday.

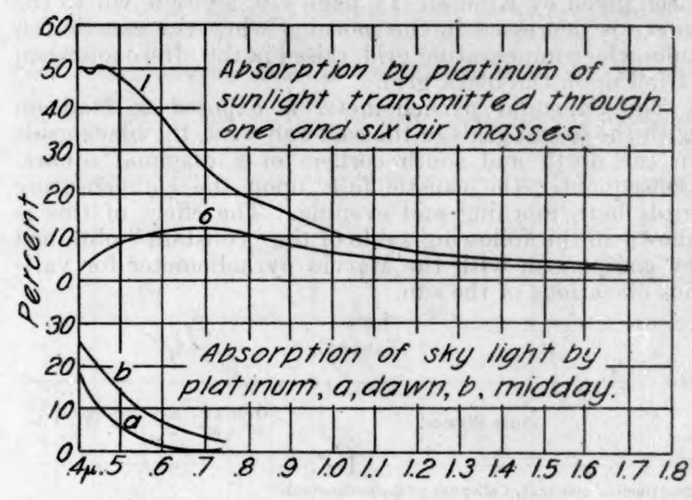

FIG. 2.—Absorption by platinum of sun and sky radiation, same scale as figure 1.

Theoretically, then, the Callendar pyrheliometer should show a decrease of sensitiveness of 5 per cent as the sun passes from 10° to 30° in altitude, and should be less sensitive to sky radiation than to solar radiation by at least 21 per cent.

Kimball ((**1**) p. 476, table 4, pt. 2) experimented with a ray filter designed to reduce the solar spectrum energy curve to approximately that of sky light. Exposed alternately to full sun light, and through this filter, the Callendar pyrheliometer showed a drop of 10 per cent in sensitiveness. But the ray filter cut off 87½ per cent of the energy of the sun, which, according to Table 1, should have increased the sensitiveness of the Callendar pyrheliometer by 17 per cent. Hence we may conclude that the Callendar is actually 27 per cent less sensitive to sky light than to sun light. The excess of this observed value over the calculated value is explainable by the absence of data as to the intensity of sky light at wave lengths less than .385μ, where the platinum absorption is known to be greatest.

The white pigments, lead carbonate, and the oxides of magnesium, zirconium, and zinc not only have the advantage of high reflection in this and other regions of the visible spectrum, but are good radiators in the long wave heat spectrum so that they would lag less than the platinum in cooling. It seems probable, therefore, that this error could be eliminated by coating the compensating grids with a white matt surface of one of these substances (**12**).

THE INTERNAL REFLECTION ERROR.

Parallel rays of light reflected from the interior surface of a cylinder or sphere, form a brightly illuminated, cusped curve that is often seen on the table cloth within a napkin ring, or water glass, and which is known as the "caustic." Such an illuminated curve is formed within the spherical cover of the Callendar pyrheliometer, and causes an error in its indications that varies with the altitude of the sun above the horizon, and according to the grid, whether thermometer or compensating, upon which the intensely localized caustic falls. Illustrations of the form of the caustic at different elevations of the sun have been given in an earlier number of the Monthly Weather Review (**11**), and a typical example of its effect on the registration of the Callendar pyrheliometer has been given by Kimball (**1**), page 479, figure 6, where the curve is depressed in the morning when the caustic fell upon the compensating grid, raised in the afternoon when it fell upon the black grid.

The Callendar pyrheliometer is exposed at Madison with the bright grids in the east and west, the black grids in the north and south corners of a diagonal square. Consequently the caustic falls upon the compensating grids both morning and evening. The effect of this is shown in the following table of the "constant" obtained by comparison with the Marvin pyrheliometer for various elevations of the sun.

TABLE 3.

Sun's altitude.	Over 55°.	55°–35°.	35°–25°.	25°–20°.	20°–15°.	Under 15°.
Instrumental constant, Callendar pyrheliometer calories per cm^2 per min. per inch of ordinate	.351	.345	.361	.350	.408	.502
Sensitiveness relative to Callendar's constant of .350	100	102	97	100	86	70

It is much more desirable to eliminate than to correct for so variable an error. Theoretically the caustic extends only half the radius from the spherical surface toward the center. The receiving grids should therefore be confined to an inner circle of half the radius of the inclosing glass.

COVER GLASS ABSORPTION ERROR.

The glass cover selectively absorbs both the ultra violet and the infra red portions of the spectrum of the incoming radiation from the sun and the sky. It also absorbs all of the energy radiated by the grids. In consequence of these facts, Kimball (**1**, p. 475) found that removal of the cover increased the sensitiveness of the instrument by 10 per cent and Ångström (**12**) found that when the ventilation of the glass cover is poor, as in calm, sunny weather, the grids do not cool, because the glass cover, to which they must radiate, remains hot, and the instrument may on this account be in error as much as 10 per cent. Another consequence of the opacity of the glass for long-wave radiation is that the grids remain at equal temperatures all through the night from sunset to sunrise.

GRID FORM ERROR.

The measurement of the vertical component of sun and sky radiation implies its interception upon a horizontal plane surface. Neither pair of grids in the Callendar pyrheliometer precisely satisfies this condition. The surface of the black grid is wavy and only roughly approximates a plane surface, while the bright grids are made up of cylindrical wires.

LAG.

The indications of the Callendar apparatus are affected by thermometric lag in the receiver and by mechanical lag in the recorder. The definition of thermometric lag by Harper (**13**) may be restated for the pyrheliometer in the following form:

If a pyrheliometer has been exposed for a long time to a stream of radiation whose intensity is rising at a uniform rate, the lag is the number of seconds between the time when the radiation stream attains any given intensity, and the time when the pyrheliometer indicates this intensity. In other words, it is the number of seconds that the pyrheliometer lags behind the radiation.

The quantitative determination of the lag is more easily arrived at by using another interpretation, viz: If the pyrheliometer be exposed to constant radiation, after having been exposed to radiation of a different intensity, the lag is the number of seconds in which the difference between the indication of the pyrheliometer and the intensity of the radiation to which it is newly exposed is reduced to ϵ^{-1} times its initial value. The value of ϵ^{-1} being approximately .368, the lag of a pyrheliometer is easily found by alternately shading and exposing it, and counting the number of seconds that elapse from the moment the intensity of the radiation is changed until the indicated radiation reaches 63 per cent of the whole change of ordinate. Experiments with the pyrheliometer at Madison in August, 1919, gave a value of two minutes and sixteen seconds for the total lag. The galvanometric and mechanical lag of the recorder, determined separately by displacing the pen carriage accounts for 20 seconds of this. The remainder is due to the thermal capacity of the receiving grids, and of the glass cover, to the extent that it acts as a secondary source of radiation. Study of the traces in experiments in which the Callendar pyrheliometer has been suddenly shaded, or exposed, (such experiments have been made at intervals since March, 1913) shows that the lag has always been about 2 minutes.

The lag error of the pyrheliometer at any time can be determined from the slope of the trace, by making use of the fundamental equation of thermometric lag, viz:

$$\frac{\partial \theta}{\partial t} = \frac{1}{\lambda}(\mu - \theta)$$

where μ = intensity of vertical component of radiation from sun and sky.
θ = intensity indicated by pyrheliometer.
λ = constant of lag.
t = time.

$\frac{\partial \theta}{\partial t}$ is the slope of the trace, while $\mu - \theta$ is the difference between the true and the indicated values of the radiation. The error of the Callendar pyrheliometer at Madison corresponding to various angles of slope is as follows:

TABLE 4.

Angle of slope of trace.	Error due to lag.
°	*Calory per cm^2 per min.*
5.4	.001
43.6	.010
84.0	.100
89.6	1.000

While these departures from the true value affect the indicated value at any instant, and are therefore of great importance in making comparisons, yet the fluctuations of the stream of radiation are so continual that the pen of the instrument keeps somewhere near the true mean value, integrating the minor fluctuations so that the indicated sum total for an hour or a day is not appreciably affected by lag.

TOTAL OR RESULTANT ERROR.

For solar radiation, the constant supplied by Prof. Callendar for Receiver No. 9864 is shown by comparison with the Marvin pyrheliometer, to be approximately true for solar altitudes above about 20°. For sky light the sensitiveness of the instrument is very much lower, but the proportion of sky light in the total at noon on very clear days is only about 10 per cent. The proportion of sky light in total radiation increases as the sun descends. The average net error for blue sky (selective absorption error minus scale error) is estimated by Kimball (1, page 480) to have the effect of diminishing the indicated radiation below the true radiation by about 2 per cent when the sky is cloudless, by 1 per cent when the sky is half clouded. On overcast days the internal reflection of sun light, and the selective absorption of sky light are both in abeyance, and the intensities are low, so that the scale error is large. The results of comparative observations between the Callendar pyrheliometer, and the Smithsonian pyranometer (uncorrected for difference between its scale and that of the Marvin pyrheliometer) are shown in figure 3 for a clear day, September 16, 1919, and a very cloudy day, September 18, 1919. It will be seen that on the clear day, from 2½ to 5½ hours after noon, the Callendar indications are depressed below the pyranometer by about 10 per cent, but that the difference diminished as the sun went down. On the overcast day, the scale error is seen to raise the Callendar indications above the pyranometer by 15 or 20 per cent.

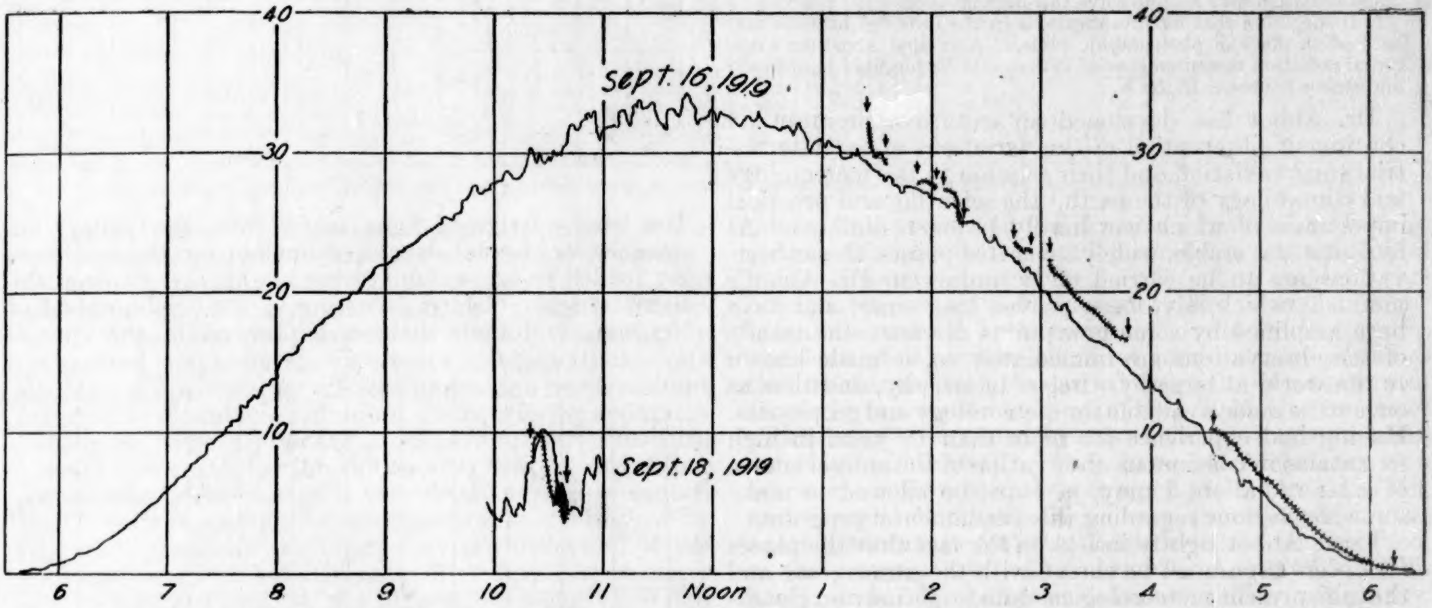

FIG. 3.—Comparative observations, Callendar pyrheliometer, and the Smithsonian pyranometer, on a clear day (September 16, 1919) and on a densely cloudy day (September 18, 1919).

ACKNOWLEDGMENTS.

I am under great obligation to Dr. H. H. Kimball, of the Solar Radiation Investigations Section of the Weather Bureau, for cooperation in the work reported above, for furnishing data used, and for reading the manuscript. Assistants in the Weather Bureau Office at Madison from 1911, and especially Mr. W. J. Summerville, have helped me in making simultaneous readings of instruments.

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SUGGESTIONS CONCERNING DR. C. G. ABBOT'S PROGRAM FOR FOUR WORLD OBSERVATORIES FOR THE OBSERVATION OF EXTRATERRESTRIAL SOLAR RADIATION.

By C. Dorno.

[Davos, Switzerland, May 21, 1920.]

SYNOPSIS.

The scientific and practical importance of the above program is emphasized. On account of the inadequacy of existing meteorological records, special observations, including detailed cloud records, are necessary before sites for solar observatories are finally decided upon. To obtain these cloud records an instrument, which has been employed at the Davos observatory since October, 1919, for recording the illumination of a horizontal surface by the sun and sky may be utilized.

Since, at night, the radiation to the sky varies with zenith distance but not with azimuth, it becomes possible to use for the measurements a blackened hollow sphere as an absolute black body, such as Ångström's "Tulipan." This seems to meet Abbot's objection that the absorption of blackened surfaces for wave lengths greater than 15 μ is not well known, and, in consequence, measurements by instruments like Ångström's pyrgeometer contain an unknown error. Comparisons between the pyrgeometer and the Tulipan, however, show a reasonably constant ratio.

The importance of ascertaining the ozone content of the atmosphere is emphasized, and it is pointed out that photoelectric intensity measurements with the cadmium cell of the spectrally decomposed ultra-violet radiation may help to solve this difficult problem.

It is suggested that for investigations in the infra-red bacteria may be used in place of photographic plates. Also, that Ångström's nocturnal radiation measurements of 1913 should be repeated in optically undisturbed times.—*H. H. K.*

Dr. Abbot has developed an extensive program for continuous observation of the variations of extra-terrestrial solar radiation and their relation to the meteorology and climatology of the earth,[1] the scientific and practical importance of which can hardly be overestimated. At four most favorable, widely separated points, these observations are to be carried on according to Dr. Abbot's methods, which have been proved long since, and have been amplified by some new points of view; the results of the observations are immediately to be made known to the world at large by wireless telegraphy, and thus at once to be made available for meteorology and geophysics. Having had experience for more than 15 years in high mountains in continuous observation of the annual course of solar radiation, I may, perhaps, be allowed to make some suggestions regarding this fundamental program.

First. Abbot rightly insists on the fact that the places for observation must be chosen with the utmost care and that the present meteorological data, especially on cloudiness, is not sufficient for decisive conclusions. It is therefore necessary to begin with careful observations of the cloudiness at the places in question. Abbot gives a description of a relatively simple instrument for registering the cloudiness photographically. At intervals of a quarter of an hour the instrument photographs the sky, which is reflected upward by a sphere.

Perhaps an instrument, which since October, 1919, has been in continuous use at the Davos observatory, and which also serves other purposes, may offer greater accuracy. It registers permanently the illumination of the horizontal surface by the sun plus the sky, and is based on the photoelectric principle. A highly evacuated potassium cell is horizontally exposed under a well-chosen filter and a dense plate of milk-glass, which diffuses the incident rays, in a case which shelters it against precipitation and disturbances of isolation; the photocurrent which is conducted through a mirror-galvanometer is photographically registered. Thus, it was experimentally made possible—not without much effort—to find a combination of cell, filter (Schott F 5899)[2] and milk-glass, that offers a curve, which, through all the variations of cloudiness, brightness, and altitude of the sun, comes satisfactorily near the physiological brightness curve that acts upon the human eye. The normal curves, resulting from regular observation series carried on for many years,[3] together with very numerous comparable photometric measurements, furnish the authority for this statement.

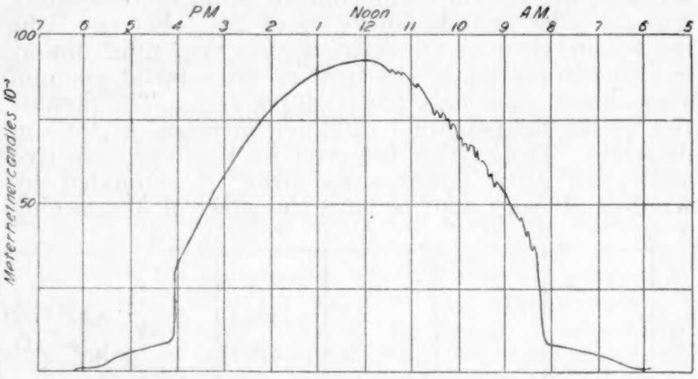

Fig. 1.—Total illumination on a horizontal surface at Davos, Mar. 4, 1920. (True solar time.)

The least vestige of light vapor from the valley, for instance, occasional streaks of smoke from the neighboring health resort, cumuli rising in the sky, or even the slightest trace of cirri occurring in the neighborhood of the sun, find their distinct expression in the curves.

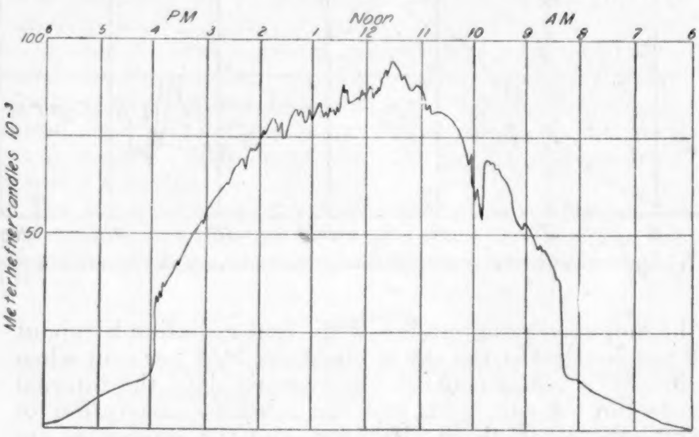

Fig. 2.—Total illumination on a horizontal surface at Davos, Mar. 3, 1920. (True solar time.)

An original curve of March 4, 1920, of a perfectly cloudless day, on which, in the forenoon, some vapor from the valley rose to the height of the observatory, and that of March 3, 1920, when the degree of solar brightness oscillated between S_3 and S_4 on account of very light, changing, high sheet of clouds, cloudiness degree B_{3-5}, are shown by figures 1 and 2. In these curves it is interesting to notice the rapid rise and fall on the appearance of the sun and its disappearance behind a mountain. The monthly numbers set up according to diurnal hours (true solar time) are given in Table 1, first, for all days without distinction, second, for cloudless days.

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[1] *Proceedings of the National Academy of Sciences of the United States of America.* Vol. 6, No. 2, February, 1920.

[2] *Physikalische Zeitschrift,* 1917, p. 381.

[3] *Studie über Licht und Luft des Hochgebirges,* Vieweg, 1911.

TABLE 1.—*Monthly means of the illumination of a horizontal surface, by hours.*

[Meterhefnercandles 10^{-3}.]

ALL DAYS.

Month. \ Sun's hour angle.	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	Mean of the days of 24 hours.	Mean maximum.	Abs. maximum.	12^h Abs. maximum.	12^h Abs. minimum.
1919.																					
October (3d decade only)				5.3	19.3	42.2	53.4	59.6	58.1	49.2	32.8	17.7	5.1	0.2			14.27	80.3	118.5	92.7	31.0
November				1.9	10.0	24.4	34.7	42.3	40.2	35.4	26.9	12.6	3.1				9.65	54.0	86.7	86.7	18.9
December				0.6	5.8	14.6	26.5	33.1	32.9	28.1	19.9	7.9	1.0				7.09	42.7	69.8	62.6	*5.7
1920.																					
January				1.5	8.7	20.3	34.7	41.1	41.1	33.8	22.6	9.5	2.0				8.97	50.4	86.1	62.4	14.7
February			0.6	4.6	15.3	40.1	55.3	64.1	64.7	57.3	44.3	21.5	5.3	0.6			15.57	75.9	102.9	88.2	30.7
March		0.3	5.0	16.9	42.3	60.3	75.4	82.4	85.8	75.1	63.5	45.5	18.2	5.3	0.5		24.02	106.1	149.6	113.9	39.9
April		4.0	17.6	36.5	57.3	73.3	88.3	90.6	81.6	74.9	66.1	52.9	33.0	12.5	3.9		28.85	118.3	163.2	146.2	30.5
May (1st decade only)	1.0	9.0	24.9	45.5	71.5	91.4	92.0	97.3	90.8	83.6	74.2	53.4	37.4	18.8	7.5	1.3	33.32	146.4	158.0	156.4	45.3

CLOUDLESS OR ALMOST CLOUDLESS DAYS.

Month.	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	Mean of the days of 24 hours.	Mean maximum.	No. of days.	12^h Abs. maximum.	12^h Abs. minimum.
1919.																					
October (3d decade only)				6.0	22.8	51.0	68.3	80.8	81.6	69.4	50.9	25.7	6.6	0.6			19.32		†5		
November				1.8	9.8	29.6	49.6	58.1	58.5	49.1	33.3	13.4	2.6				12.74		6		
December				0.7	5.0	18.6	37.4	45.5	45.2	37.3	24.0	8.3	1.1				9.29		10		
1920.																					
January				1.4	8.7	23.7	44.5	53.3	53.3	44.6	29.2	10.3	1.9				11.29		12		
February			0.5	4.1	14.5	42.4	59.3	68.8	69.9	61.9	46.5	23.0	5.0	0.6			16.52		15		
March		0.5	5.7	20.0	51.0	73.8	90.2	101.2	101.8	90.7	73.6	54.5	21.5	6.7	1.8		28.88		11		
April		4.9	19.8	46.4	75.8	98.9	117.3	125.6	126.2	118.1	95.6	71.2	45.5	16.6	4.2		40.25		3		
May (1st decade only)	1.3	11.3	33.1	60.7	87.6	108.9	124.7	136.7	138.9	131.2	114.9	89.5	58.8	25.7	9.4	1.3	47.25		†3		

* 23 December (a day of uninterrupted thick snowfall, grown famous on account of the tremendous avalanches that came down on Davos). † Decade.

The only part of the apparatus that is costly is the photographic registry contrivance and the galvanometer; if once rightly constructed and calibrated, it needs for its manipulation only a careful hand, not a highly trained one. According to my experience of many years, highly exhausted cells maintain sufficient constancy, if carefully handled, provided they are not charged too much and not exposed to too intense radiation; the registering apparatus which has been in permanent use here for seven months, proves this anew, for the curves are checking each other constantly. The change is very small, 4 volts in winter, and 2 volts in summer; the intensity is so diminished by the milk glass and the filter, that the deflection of the galvanometer (of sensitiveness 10^{-9} amp.) at a meter distance is 110 mm. at the highest. Among other advantages, this instrument not only registers the cloudiness but records any other opacity of atmosphere, especially the dust content, which, in dry deserts (and in such places, dust seems to be the chief consideration), would be more dangerous to the observations than cloudiness. Disturbances by water vapor would not be less feared, and, for this reason, the tropical countries and especially all small, isolated islands in the ocean should be avoided. Places far distant from the sea, situated on a high plateau, if possible with a perennial snow covering or, at least, one lasting for many months, afford probably the most favorable points for observation, unless the cloudiness too often hinders.

Second. Concerning the absorption by the atmosphere of very long-wave radiation, which is so important for the intensity measurements of terrestrial radiation, Abbot insists on the fact that for the wave lengths greater than 15μ the absorption of the surface of the instruments in use to-day has not been sufficiently investigated, and that especial importance should be attached to the exact determination of the ozone-content of the air, although there is but little in the lower strata of the atmosphere. There are two reasons for this: First. Ozone is especially absorptive of those wave lengths (about 10μ) which prevail in the terrestrial radiation; second, this absorption band lies outside the absorption bands of water vapor, while the absorption bands of carbon dioxide contained in the atmosphere to a much larger extent than ozone, coincide with those for water vapor.

As far as other investigations have permitted, radiation measurements were carried on at the observatory of Davos in the winter seasons of 1911–1913, the results of which have been added in a preliminary way to a more extensive publication.[4] They have been taken up in a new and more systematic way since the autumn of 1919, and especial importance has been given, first, to the exact determination of the absolute values, and, second, to the proportion of values which K. Ångström's "Tulipan" and "Pyrgeometer" furnish. The integration values of effective radiation (R) through the whole night, from the end of the astronomical evening twilight to the beginning of astronomical morning twilight, measured by Tulipan, the values of computed radiation of a black surface (S), the radiation of the atmosphere of given temperature (E), and of 20° C. (E_{20}) for the nights with the smallest radiation of the atmosphere, are contained in the following table, by months:

TABLE 2.—*Nocturnal radiation measurements, October, 1919–May, 1920.*

[Monthly minima of E_{20}. Integration values of the whole night.]

Date.	Temperature.	Abs. humidity.	R.	S.	E.	E_{20}.
1919.	*°C.*	*g/m.*³	*cal.*	*cal.*	*cal.*	*cal.*
Oct. 30	−10.9	1.27	0.182	0.394	0.212	0.331
Nov. 3	− 8.4	1.58	.178	.409	.231	.347
Dec. 11	−12.2	1.11	.183	.386	.203	.324
1920.						
Jan. 25	− 3.9	1.83	.180	.438	.258	.362
Feb. 8	− 8.2	1.09	.205	.411	.206	.309
Mar. 4	+ 2.0	2.73	.216	.477	.261	.337
Apr. 3	− 4.7	2.10	.174	.433	.259	.369
30	+ 3.2	3.45	.195	.486	.291	
May 6	+ 0.1	2.84	.183	.465	.282	.374

R = Effective Radiation.
S = Computed Radiation of a black surface.
E = Radiation of the atmosphere of given temperature.
E_{20} = Radiation of the atmosphere of 20° C.

[4] *Abhandlungen des Preuss. Meteorolog. Inst.* Bd. VI, 1919.

The adopted radiation constant is $\sigma = 8.35 \times 10^{-11}$ gr. cal. per mm. per sq. centimeter.[5] The E-values are lower than those obtained by interpolation from A. Ångström's "Table for Nocturnal Radiation at Various Altitudes."[6] (For an elevation of 1,600 m. and a temperature of $+12°$ C., $E = 0.33$ cal., $E_{20} = 0.37$ cal.). This seems to indicate an especially dry and pure atmosphere and adds a new proof to the many already existing for the continental character of the climate of the Swiss Eastern Alps Plateau. The ratio $\frac{\text{Tulipan}}{\text{Pyrgeometer}}$, as determined during the months of September, 1919, to May, 1920, on clear nights with changing movement of the air and changing vapor content, which rose frequently in the calmness of the winter night as finest haze hardly visible to the eye, as shown in the following table:

TABLE 3.—*Ratio* $\frac{\textit{Tulipan}}{\textit{Pyrgeometer}}$.

Date.	Sun's hour angle.		Ratio.	Clouds 0-10.	Wind.	Remarks.
1919.	*H. m.*	*H. m.*				
Sept. 24	6 55	8 09	1.21	0-4	C	
Sept. 26	7 02	8 07	1.43	0	S'	
Oct. 4	6 40	8 14	1.37	0	C	
Oct. 10	7 13	8 12	1.39	0	C	
Oct. 18	6 18	8 07	1.52	0	C	≡°
Oct. 30	6 00	7 45	1.37	0	C	
Nov. 28	5 54	7 19	1.32	0	C	
Dec. 2	5 19	6 52	1.39	0	C	
Dec. 11	5 51	7 10	1.47	0	C	V°
1920.						
Jan. 19	5 35	7 48	1.32	0-1	C	
Feb. 5	5 18	7 41	1.37	0	C	
Feb. 18	6 05	8 01	1.48	0	C	Sometimes smoky.
Feb. 25	6 39	8 32	1.29	0	C	
Mar. 1	6 30	7 42	1.39	0	C	
Mar. 22	6 46	7 44	1.40	0	N'	
May 11	8 06	9 07	1.40	0	C	

The gauge factor, introduced in comparative calculation, is that furnished with the Tulipan by the Physical Institute of Upsala and later corrected by means of the Pyrgeometer factor. It proves, as has already been supposed[4] to be much too high. For the present consideration it is important that the ratio Tulipan/Pyrgeometer be, to a satisfactory extent, constant. The variations found by comparing the integration values and single values measured every ten minutes can hardly be expected to be smaller, especially if we consider that it lies in the nature of the Tulipan instrument to be behind hand, that every single drop is formed but slowly, and that it depends on chance whether the measuring takes place immediately before or after the fall of a drop. It will be possible to infer from these comparative measurements whether a sufficient constancy of ratio between the two types of Ångström's instruments does already exist or may be attained by a slight correction. This is very important for two reasons: First, it proves anew that the distribution of radiation over the night sky is much simpler than over the day sky, because, on the whole, the radiation increases from the zenith to the horizon independently of the azimuth, and in close relation to the intensity of the radiation, so that it suffices to measure only a small area near the zenith; second, it enables us to use for the measurement (as K. Ångström does by "Tulipan") a blackened hollow ball as an absolutely dark body, whereby the serious doubt existing on account of the possible loss of the radiation of the wave lengths greater than 15μ, is done away. It is true, the existing Tulipan instrument seems to answer all the requirements relating to this, and it also possesses the great advantage of not being influenced by convection, or at least very little so, and to react but slightly on oscillating air movements.

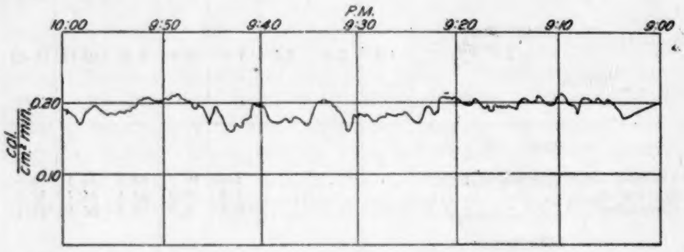

FIG. 3.—Nocturnal (effective) radiation at Davos, Feb. 18, 1920. (True solar time.)

Eliminating the compensation, some continuous registerings have been carried on with the pyrgeometer in Davos during entirely calm winter nights. The thermocurrent generated between the bright and black strips on account of the effective radiation is conducted through a mirror galvanometer and registered. A sector of the curve of February 18 follows:

In spite of the not inconsiderable variations produced chiefly by the descent of cold air from the mountain slopes to the bottom of the valley the nocturnal course of effective radiation is, in this kind of curves, to be recognized by values which are at first rapidly increasing, then remain stationary, and at the beginning of dawn are slowly decreasing. The decline of the curve in the above figure between about 9:22 p. m. and 9:32 p. m. is surely due to the smoke rising from a neighboring building, and the following second decline is probably due to the same cause. The accuracy of this method of measurement may be inferred thereby.

While in this way the doubts about the existing radiation of wave lengths greater than 15 μ, which until now have not been measured may be removed by an instrument similar to Tulipan, at least as far as the nocturnal service of the instrument is concerned (I already pointed out the reasons which make its use impossible by day[4]), it is certain that the determination of the variations in the ozone content of the atmosphere remains a very difficult problem. The ultra-violet continuous spectograph which Zeiss constructed at my request[3] shows in the ultra-violet the absorption lines very clearly (the reproduction on page 15 is unfortunately not good), and it seems unquestionable that with a greater dispersion the breadth of the lines and their brightness contrast will offer an accurate means of obtaining the ozone content, though the numerous absorption lines in the ultra-violet arising from other elements will always render the problem a rather difficult one. With sufficient instrumental auxiliaries, the photoelectric intensity measurement with the cadium cell in the spectrally decomposed ultra-violet would furnish the necessary control and supplement, and it promises full success. For five years I have had very satisfactory results with the effect of the total ultra-violet sun radiation below 0.366μ on this cell.

I make use of the present occasion, in discussing the ozone effect to draw, with all due reserve, attention to the fact that according to the investigations made by J. Maurer and myself on the geographical extent of the Katmai disturbance,[7] and which I continued by my comprehensive measurements of polarization and brightness of the sky[4] and supplemented by my observations on twilight and ring phenomena[8] during the years 1912–1914

[5] *Meteorologische Zeitschrift*, 1919, p. 45.
[6] *Smithsonian Miscellaneous Collections*, Vol. 65, No. 3, 1915. *Meteorologische Zeitschrift*, 1916, p. 534.

[7] *Meteorologische Zeitschrift*, Meteorologische Zeitschrift, 1914, p. 49.
[8] *Abhandlungen des Preuss. Meteorolog. Inst.* Bd. V, No. 5, 1917.

on the gradual decreasing of the disturbance, there exists the probability that at the time of A. Ångström's measurements in California (August/September, 1913)[6] there were also dust masses prevailing in the higher atmospheric strata. Considering the great theoetical importance Ångström's final results have for the understanding of the radiation of the highest atmospheric strata[9] and, what is of more immediate interest, for their ozone content, depending undoubtedly on the degree of sun's activity, new measurements in optically undisturbed times will be needed.

I may be allowed to point out another fact: If A. Ångström's new actinometer for sky radiation[10] proves useful and magnesium oxide really very well absorbs the wave lengths greater than 4μ, then the necessary means to shelter the Stevenson shelter against radiation influence would be found. Long series of observations not yet published have proved how much the shelter needs this protection in a genuine radiation climate like that of Davos, where intense radiation is combined with low air temperature. The following unpublished figures will show that in these conditions of radiation color offers but little protection to the raw material beneath it. The experiments were made in the period from October, 1913, to January, 1914 (that is to say, low sun altitude), with hollow boxes of wood of cylindrical shape 3 cm. high and 2 cm. in diameter set up in a place entirely protected against reflected radiation and wind and free on all sides. They were filled with mercury to a level where the sun's rays could not strike the surface. In this mercury the thermometer bulb was freely suspended. The boxes were painted in the following colors: White, pink, yellow, red, and black. The result obtained was as follows. The addition of a calorie of radiating heat produced the following rise of temperature:

	°C.
White	10.8
Pink	11.0
Yellow	14.8
Red	15.7
Black	16.9

What is remarkable in this is the fact that wood remains a great heat collector also when it is painted with best reflecting white color, and that the color does not have so great an effect as is generally believed; for the dark color only adds 6° to the 11° temperature increase which the wood undergoes under the white paint. It is therefore more important that the material of the building be well chosen than the color. When absolute calm prevails, the temperature of the air is not of great influence during this one-sided insolation, but with the air in movement loss of heat sets in through conduction, and 30 per cent of the irradiating heat (roughly speaking) is lost when the air movement is slight, and 60 per cent when the movement is of mean degree. With the more strongly absorbing dark colors this loss is noticeably slower than with the light ones. If, on the other hand, reflex radiation from light walls of the neighborhood intervene, the unchanged free exposure being continued, that is to say, the box of wood being on all sides washed by the air the heat increase of the dark colors amounts to one-third, that of the lighter ones to one-fifth. If the increase of heat radiation ceases at sunset, the temperature of the dark colors decreases quicker, according to their greater surplus over the temperature of the ambiant air, especially for the first 10 minutes; after 20 minutes the temperature of the dark colors exceeds that of the air about 3½° against 3½° for the lighter colors; after 40 minutes about 2° against 1°. The loss of heat is very slow as may be seen.

Finally, an exceedingly ingenious test for the investigations in infrared may be mentioned; that is, the use of bacteria which react very keenly at spectrum line's breadth. These can be advantageously substituted for the photographic plate more or less satisfactorily in this part of the spectrum.

[9] *Smithsonian Miscellaneous Collection loc. cit.* Hergesell, *Abhandl. Aeronaut. Observ. Lindenburg*, Bd. XIII, 1919.

[10] Monthly Weather Review, 1919, 47: p. 795.

A WATERSPOUT IN THE ADIRONDACKS.

The United States Weather Bureau meteorologist at Albany, N. Y., Mr. George T. Todd, has reported an interesting and unusual waterspout which was observed on Lake Newcomb in the Adirondack Mountains. On the afternoon of May 16, Mr. F. W. Kelly, of Albany, and several others observed a whirl of water which appeared to be a partly formed waterspout. The column of water was about 4 feet in height and about as large in diameter as a flour barrel. It moved across the lake from northwest to southeast, whirling counterclockwise. There appeared to be no unusual atmospheric disturbance on shore before the waterspout started, but, beginning where the water was about a foot deep and progressing across the lake where a depth of 3 or 4 feet, the spout ended with a considerable splash on the opposite shore. A depression in the water level near the spout was also observed. The center of the whirl passed within 20 to 25 feet of Mr. Kelly, but no unusual atmospheric condition was noticeable. He said there was a sound of rushing water similar to that made by turning the water from a high pressure fire hose on another body of water.—*C. L. M.*

TORNADO IN UNION COUNTY, N. C., JUNE 20, 1920.

At 2 p. m. of June 20 a tornado of considerable violence formed in the southwestern part of Union County, approximately 22 miles south-southeast of Charlotte, seriously injuring one person, demolishing eight dwellings and a number of barns and outbuildings, and inflicting considerable damage to cotton fields, crops, and timber. The total damage is estimated at about $30,000.

The storm apparently began a short distance south of the village of Waxhaw and ended at or near Wesleys Chapel, having followed a northeasterly path about 7½ miles long and about 200 feet wide.

It is possible that the inception of this tornado was witnessed by Mr. and Mrs. Rock Morrison, who were traveling by automobile from Miami, Fla., to Charlotte. At 2 p. m. of the above date they stopped at the Osceola Creek bridge to adjust a tire, and their experiences there are reported in the Charlotte News as follows:

"While the automobile was standing, Mrs. Morrison observed a small whirlwind stirring up the leaves on the top of a small hillock about a quarter of a mile away. It dipped toward the surface of the ground for a moment and appeared to lift a few feet above the surface for a moment. This was indicated by the leaves and stubble once picked up fluttering back to earth. Presently, however, there was a noticeable quantity of leaves and stubble flying in the air, and Mrs. Morrison directed her husband's attention to it.

"In a moment the tiny whirlwind had resolved itself into a swirling tornado, which became black with leaves, sticks, twigs, and limbs of trees and débris of various kinds, as it started a rapid sweep across the landscape with an ominous roar.

"Awestruck at the unusual sight, Mr. and Mrs. Morrison watched the cloud, which was clearly funnel-shaped, sweep over the country and pick up a house which it smashed, hurling bits of the shingle roof, window sash and other bits of wood high in the air. It twisted trees into tooth brushes of colossal size, and cut a swath through the forest and over fields as distinct as if some giant with a scythe had

done the work. The phenomenon swept on across the country out of sight."

Passing within half a mile of Waxhaw, the storm did no damage there, but seems to have been at its greatest intensity 2½ miles northeast of that place, in what is called the Howie Gold Mine district.

Here the home of B. P. Hancock was completely destroyed, and one of the children, Ella Hancock, seriously injured by flying timbers. The other members of the family sustained minor injuries. Two tenant houses in this vicinity were wrecked, one of which was occupied by Raymond Paxton and his family. That no one was injured is probably due to Mr. Paxton's precaution in taking his family to a deep road ditch, in which they lay flat.

At the Howie mine a negro cabin was demolished, the occupants having taken refuge in an old mine shaft. The old mill house was blown down on five mules, one of which was killed and others injured. A yearling heifer was also killed. Large oak trees were twisted and torn out by the roots, the tramway from the shaft to the mill house was wrecked, and roofs and chimneys of other buildings were blown off.

From the Howie mine the tornado continued northeastward for about 4 miles through a sparsely settled district, apparently coming to an end near Wesleys Chapel, which is 8 miles southwest of the place where the April tornado began.

The following descriptions of weather conditions attending the movement of this tornado have been received:

From Lewis L. King, postmaster at Waxhaw, N. C.:

"I saw the tornado that passed this town on Sunday, June 20, 1920, from beginning to end. It was a typical summer day, warm, with thunder clouds passing over. A heavy thunder cloud had passed to the north of us, going northeast, a few minutes before the black funnel-shaped cloud appeared, but there was just a light rain in the cloud that passed before the tornado and not much rain in the tornado cloud. There was a mighty roar, somewhat like the roar of a train, and some people actually mistook the noise for a passing train and did not see the tornado. I would say that the path of the storm was not over 200 feet. There was no thunder in the tornado cloud. This was a genuine twister, which suddenly dipped down and was exactly in the shape of a funnel."

From B. P. Hancock, living 2½ miles northeast of Waxhaw, whose home was completely demolished:

"The forenoon was very hot, with a few showers. About 1:30 a small cloud formed in the southwest, moving southeast, and about 20 minutes later another small cloud formed in the northwest, moving toward the northeast, from which thunder was heard three times. After the third thunder it seemed to move back to the southwest, forming into a body like a thunderhead and an awl at the same time. At times it fell to the earth and then rose back up again, and soon formed into a funnel shape, broad at the top and narrow at the bottom. This descended down again and it began to roar and move from the southwest to the northeast. It was dark in the storm as night, but there was no thunder, rain, or hail; there seemed to be a lot of heat inside it."

It is interesting to note that both of these accounts describe the weather as "warm" and "very hot," whereas in Charlotte it was rather cool in the forenoon, the temperature ranging from 62 to 65 up to 11 a. m., when it began to rise, reaching a maximum of 78 at 4 p. m. Cool weather prevailed generally throughout the State, the maxima in the central district ranging from 65 at Winston-Salem to 80 at Albemarle. Monroe, about 10 miles east of the tornado path, had the highest maximum, viz, 83. The heat area mentioned in the above accounts was, therefore, purely local.

There was a thunderstorm in Charlotte from 5:05 p. m. to 6:22 p. m., and frequent showers occurred during the day, the total amount being 1.11 inches. One of these showers occurred from 1:05 p. m. to 1:50 p. m.; amount, 0.31 inch.

Monroe reported a rainfall of 0.62 for the day.—*G. S. Lindgren, Weather Bureau Office, Charlotte, N. C.*

TORNADO IN SOUTHEASTERN WYOMING, JUNE 24, 1920.

The Weather Bureau official at Cheyenne, Wyo., has reported the occurrence of a small tornado, accompanied by a severe hailstorm in southeastern Wyoming on the afternoon of June 24. As far as can be learned, the damage was very slight. The tornado swept a path about 200 feet wide and about 12 miles long in the vicinity of Hillsdale and Burns. A few houses, barns, and fences were destroyed, but there was very little damage to stock and no deaths were reported.

The hailstones were unusually large and destructive. Several newspapers contain accounts of hail "as large as good-sized lemons," "medium-sized hen's eggs," English walnuts, and one report from Burns said the hailstones were about 7 inches in circumference. The force of the hail was sufficient to dent the steel roof of railway coaches and did considerable damage to tin roofs. On the whole, however, the storm was not severe, although in appearance it was said by some former residents of the Missouri valley to be a "regular, old-time Missouri twister."—*C. L. M.*

COLD SHORE WATER OWING TO OFF-SHORE WINDS.

By CHARLES F. BROOKS, Meteorologist.

[Weather Bureau, Washington, D. C., July 28, 1920.]

Reports of unusually cold surf bathing along the New Jersey coast late in July, 1920, led me to examine the wind records of Sandy Hook and Atlantic City. Although there had just been a decidedly cool spell, with northerly winds, and although the spring and early summer averaged 2° or 3° F. below normal in eastern New Jersey, it did not appear that these influences would be sufficient to make the coldness of the water worthy of remark. An unusual amount of off-shore wind, however, would easily account for cold water, because such winds would have driven the warmed surface water out to sea, and cold water from below would have replaced it.

In June, 1920, the off-shore winds—SW., W., NW., and N.—at Sandy Hook blew a total of 4,778 miles, as compared with 2,260 in 1919, and 5,148 in 1918. It is noteworthy that these winds in June, 1920, comprised 54 per cent of all the wind of that month, and that this is not only markedly greater than the 26 per cent of off-shore winds in June, 1919, but also exceeds the off-shore winds of June, 1918, which were 49 per cent of the total—less than half, in spite of the large amount, June, 1918, being unusually windy.

At Atlantic City the average (1914–1920) frequency of off-shore winds, SW., W., NW., and N., at the 8 a. m. and 8 p. m. observations in June is 28, i. e., 47 per cent. In June, 1920, however, the number was 38, or 63 per cent of the total. In July the average frequency of off-shore winds is 34 (31 for 28 days), or 57 per cent, while in the first 28 days in July, 1920, the number of off-shore wind occurrences was 37, or 66 per cent. Thus, in June and most of July this year the off-shore winds have been 27 per cent more frequent than the average of the last seven years, and have occurred about two-thirds of

the time. Not since 1912, when the off-shore winds of June and July were 26 per cent more than the average, has there been even as much as 10 per cent more than the usual frequency of off-shore winds in June and July combined. In June and July, 1919, the on-shore winds, NE., E., SE., and S., were 26 per cent more than the average frequency.

In view of the very unusual frequency and preponderance of off-shore winds on the New Jersey coast during the past two months, it seems reasonable to ascribe the reported coldness of the water to their action in blowing the warm water out to sea.

Addendum (Aug. 13).—A letter recently received from Mr. W. H. Culliman, of the Boston Globe, states that "The temperature of the water at New England beaches [Massachusetts particularly] has been consistently about 10 degrees below normal this season, according to reports from the State bathhouses." As in the case of the New Jersey coast, though to a greater degree in New England, the water probably has been colder than normal since the cold weather of last winter. Add to this the effect of a reduced amount of warming in June, owing to 25 per cent more than normal cloudiness at Boston (19 per cent excess at Nantucket), and we have the cold water partly explained.

The unusually persistent offshore winds (i. e., SW. to N.) have blown even the moderately warmed surface water out to sea and cold water has welled up from below to take its place. Wind data for Boston and Nantucket, tabulated with the help of Mr. Herbert Lyman, show that in June and July this year there was 10 per cent more offshore wind than in the corresponding period of last year. At Boston 74 per cent of all the wind in these two months was offshore (69 per cent last year), and in July alone 83 per cent—6,081 miles of wind went out to sea and only 1,248 miles came in.

Thus, cold water in spring, warmed moderately in early summer and then largely blown out to sea, has left for bathers the still colder ocean water creeping up from the depths of the Labrador current.

NOTES, ABSTRACTS, AND REVIEWS.

THE BLUE SKY AND THE OPTICAL PROPERTIES OF AIR.

By the Right Hon. LORD RAYLEIGH.

(Abstracted from Nature, vol. 105, pp. 584-588, July 8, 1920.)

The late Lord Rayleigh, from his demonstration that upon the basis of either the elastic-solid or the electromagnetic theory a cloud of small particles (individually minute relative to the wave-length) is capable of scattering incident light in every direction, the scattered light being preponderately blue and completely polarized in a direction at right angles to the source, was led to the conclusion that the air molecules alone were capable of accounting for much, if not all, of the blue light of the sky. Tyndall's experiments upon the disappearance of the path of a beam of light when the motes were removed by filtering through packed cotton-wool or by being consumed in the flame of a Bunsen burner under the beam seemed to refute this. The present Lord Rayleigh, however, has shown, by visual, photographic, and spectroscopic observations, that the path of a beam through dust-free air (and there is no trouble about removing all the dust—dust so fine as to be very difficult of filtration is an armchair conception not encountered in practical experimenting), when *observed transversely against* a sufficiently black background (e. g., the mouth of a deep cave) to get rid of stray light, is distinctly visible, and blue. It seems to appear to be of other colors, e. g., lavender, to some people because, probably, of a peculiarity of color vision with faint light.

Observation has, however, detected for each gas a characteristic departure (4 per cent for pure air) of the scattered light from complete polarization. Theory shows that this must be due to nonsphericity of the molecules; hence such experiments may furnish material for the investigation of molecular and atomic structure.

Rayleigh and Babcock have found, by means of the Savart polariscope, that the light from the night sky shows only a trace of polarization, and hence can not be due to light from an attenuated atmosphere so high as to be outside the earth's shadow.[1]

In 1917, Rayleigh (then Prof. Strutt) and Fowler discovered that the limited extension of the solar spectrum into the ultra-violet was due to absorption bands (previously undetected because of their diffuseness and the superposition of numerous metallic lines) identical with those observed at the limit of the spectrum of Sirius by Huggins in 1890, and identical with bands in the spectrum of burning magnesium when observed through a tube containing ozone. The solar spectrum has a greater extension in the ultra-violet with a high sun than with a low sun. Of oxygen, nitrogen, carbon dioxide, water vapor and argon, none appreciably absorbs ultra-violet rays in the region where the solar spectrum ends; and the spectrum of a mercury-vapor lamp observed 4 miles away, so that the air mass was equal to that above the Peak of Teneriffe where solar spectrum observations have been made, showed no evidence whatever of ozone absorption.

"What conclusion can we draw? Evidently that the absorbent layer of ozone in the air is high up, and that there is little or none near the ground. It may seem at first sight that this thin and inaccessible layer of ozone, which we have learned of by a chain of reasoning not less conclusive than direct observation, is a matter of little importance to man and his welfare. There could be no greater mistake. It acts as a screen to protect us from the ultra-violet rays of the sun, which without such a protection would probably be fatal to our eyesight. At least if one may judge from the painful results of even a short exposure to such rays, which those who have experienced it are not likely to forget."—*E. W. W.*[2]

[1] See H. D. Babcock, Note on the polarization of the north sky, Astrophys. Jour., 50, 228-231, 1919.—*E. W. W.*

[2] It may be pointed out that if the absorptive layer of ozone did not exist, the course of organic evolution during the geologic ages would have been such that the resulting organisms whould have been adapted to withstand the ultra-violet radiations.—*E. W. Woolard.*

THE LIGHT FROM THE SKY.

The color of the cloudless sky, though generally blue, may, according to circumstances, be anything within the range of the spectrum. The early attempts to account for the blue of the sky were mere speculations; the first logical attempt was that of Newton, but it was erroneous, and criticized by others.[1] The discoveries of

[1] See W. J. Humphreys, Optics of the Air, Jour. Frank. Inst., November, 1919, p. 657 et seq.

Arago (in 1811) and of Brewster, relative to sky polarization, and the experiments of Brücke and of Tyndall[2] first indicated the true explanation, and later the necessary theory was supplied by Lord Rayleigh.[3] The conclusions of the latter have been verified by King,[4] Cabannes[5] (who was the first to observe the scattering of light by dust-free air), Lord Rayleigh (then Prof. Strutt), who made a very comprehensive study of the relative scattering power of different gases and its dependence upon the density of the gas, together with an investigation of the state of polarization of the scattered light,[6] and R. W. Wood.[7]

On the subject of the light from the night sky and whether or not it can all be accounted for by starlight; as well as whether the total light from all theoretically existing stars can satisfactorily account for the observed illumination of the night sky, a voluminous literature exists.[8]—*E. W. W.*

[2] W. J. Humphreys, loc. cit. H. H. Kimball, Jour. Frank. Inst., April, 1911, p. 344.

[3] Phil. Mag., vol. 41, pp. 107, 274, 447, 1871; vol. 12, pp. 81, 1881; vol. 47, p. 375, 1899.

[4] L. V. King, On the Scattering and Absorption of light in gaseous media, with applications ot the intensity of sky radiation, Phil. Trans., A, 212, 375–433, 1913.

[5] J. Cabannes, Sur la diffusion de la lumière par l'air, Comptes Rendus, 160, 62–63, 1915.

[6] Proc. Roy. Soc., A, 94, 453; 95, 155, 1918.

[7] R. W. Wood, Light Scattering by Air and the Blue Colour of the Sky, Phil. Mag., 39, 423-433, 1920; see Monthly Weather Review, 48, 220, April, 1920; also Monthly Weather Review, 44, 246, 1916; 45, 484, 576, 1917; 46, 70, 1918; 47, 797, 1919. On the brightness and total light of the sky, etc., see the *Annals* of the Astrophysical Observatory, Smithsonian Institution; F. E. Fowle, Atmospheric Scattering of Light, Smiths. Misc. Coll., 69, No. 3, 1918; A. F. Moore and L. H. Abbot, Brightness of the Sky, Misc. Coll., 71, No. 4; M. Luckiesh, Aerial Photometry, Astrophys. Jour., 49, 108–130, 1919; Monthly Weather Review, 47, 540, 1919.

[8] See, e. g., E. E. Barnard, On the Dark Markings of the Sky, Astrophys. Jour., 49, 1-23, 1919; W. J. Humphreys, On "Earth-Light," or the brightness, exclusive of starlight, of the midnight sky, Astrophys. Jour., 35, 273-278, 1912; E. E. Barnard, Self-Luminous Night Haze, Proc. Amer. Phil. Soc., 50, 246–253, 1911; 58, 223–235, 1919; P. J. van Rhijn, On the Brightness of the sky at night and the total amount of starlight, Astrophys. Jour., 50, No. 5, 1919; W. D. MacMillan, Astrophys. Jour., 48, 35–49, 1918; V. M. Slipher, Astrophys. Jour., 49, 266–275, 1919.

RAINFALL AT MUSCATINE, IOWA.

By WM. P. MOLIS.

The *Journal of the American Water Works Association*, for January, 1920, pages 127–131, contains an interesting and practical discussion of the use of rainfall data in the municipal water works. The data on rainfall at Muscatine covered a period from 1846 to 1918. As the author points out, "the rainfall is the source of the water supplies of our communities, and long-time records of it are invaluable in estimating the quantity of water obtainable from a surface supply and in investigations of the quantity which exists as ground water. Such data are also valuable in studies of the relation between rainfall and floods. Few who have not experienced flood difficulties realize the danger which may arise if their pumping stations and machinery are situated on low lands exposed to overflow. A rain of one week or a cloudburst will suddenly swell the streams to such a height as to make quick work by the water department necessary in order to save the plant from being put out of commission."

It was found that the average annual rain and snowfall was about 37 inches. The minimum for the period studied was 23.04 inches in 1910, and the maximum was 74.50 inches in 1851. Another interesting point is that when the average precipitation for two thirty-year periods, 1846–1875 and 1876–1915 are compared it is found that it is 2.46 inches less for the second period than the first. Unusually severe rains (at Muscatine, those over 1.5 inches in 24 hours are so regarded) are studied with a view to determining the probability of such occurrences; it is believed that if a 2-inch fall of rain does not occur at some time during the first six months of the year, it is almost certain to occur during July, August, or September. It is dangerous, of course, to place too much confidence in such frequency tables, but, when this fact is remembered, such data may be of grrat practical value to the superintendent of water works in planning to meet emergencies.—*C. L. M.*

CERTAIN ENVIRONMENTAL FACTORS INFLUENCING THE FRUITING OF COTTON.

By E. C. EWING.

[Technical Bull. No. 8, Miss. Agr. Expt. Station, 1918.]

The relation of weather and soil conditions, and of the varietal, or hereditary, factors, to the rate of fruiting and shedding are treated in considerable detail, but this review is restricted to the meteorological aspect of the problem.

A daily census of flower production, started in 1911, showed a pronounced variation in the number of flowers opening from day to day. Weather influence on this variable rate was suspected; but owing to limited meteorological data, the maximum and minimum temperatures, precipitation, and the charcter of the day as to the degree of cloudiness, no definite relation between any of these weather elements and the rate of blossoming was apparent. In 1913 additional meteorological instruments were installed, including a thermograph, hygrograph, porous cup atmometer, and a photographic sunshine recorder. In addition, soil moisture observations were made each day, first to a depth of 12, and later to 18 inches. Observations were made on this basis during that and the succeeding year, except for sunshine in 1914 when a defect in the sunshine recorder prevented observations by that instrument.

The tabulation and study of the data obtained from these observations, however, did not show any marked or dependable relation between the additional data secured and the rate of blossoming. In the case of temperature, the curve indicating the daily minimum values appeared to vary rather frequently in the same direction as the flowering curve. As a result of the studies during the four-year period from 1911 to 1914, it may be stated, but only in a very general way, that temperatures below 65° F. may be expected to decrease the number of flowers opening about two days later.

There was also some indication of agreement between the percentage of soil moisture and the flowering data, but this was less suggestive than in the case of minimum temperature. Increased soil moisture seemed to inhibit flowering somewhat, irrespective of the trend of the minimum temperature curve, as in some cases the rate of flowering was retarded after rain and increased soil moisture when the minimum temperature remained high.

The other weather elements showed little or no relation to the rate of flowering, but unfortunately, from the experimental viewpoint, no abnormalities of consequence in the weather elements prevailed; otherwise more definite results probably would have appeared. During protracted periods of cloudy and rainy weather, rank stock growth in cotton at the expense of fruit is not uncommonly observed, for under such conditions growth occurs mostly, not so much by multiplication of nodes as by the lengthening of the inner nodes.

Normal shedding, or abscission, of a variable number of immature fruits of the cotton plant is the general experience in America. It is the opinion of cotton growers that either too little or too much moisture will cause cotton shedding. From some studies made in Egypt, it has been shown that shedding becomes abundant there toward the end of the interval between irrigations and

decreases directly after waterings, but finally becomes excessive again when the water level is raised and the lower soil becomes saturated by the infiltration of flood water from the rising Nile.

In the Mississippi studies there appears to be no basis, on the whole, for assuming that temperature has any appreciable effect on shedding; but it seems from the data collected that the moisture factor is important, the data showing that an insufficient supply of moisture tends to excessive shedding. There was no opportunity, however, for observing the effect of protracted periods of wet weather, so this aspect remains to be studied. The outstanding feature of the moisture and shedding curves is the apparent relation between that for evaporation and that for shedding, in which a high rate of evaporation and decreased soil moisture frequently correspond to a rise in the shedding curve, if an arbitrarily established period of four or five days is allowed to intervene between apparent cause and effect, or for the action of the stimulus to shedding.

Reviewer's note.—In the study of the relation of weather to such ecological phenomena as the fruiting of cotton, it is unfortunate that sufficient observational data are not available for the establishment of at least an approximate normal curve, to permit of a mathematical correlation of departures from the normal weather factors, and departures from the normal frequency curve. The first flowers appear in a field of cotton from 7 to 10 weeks after planting; and production gradually, but irregularly, increases to a maximum, after which it decreases in like manner to the close of the flowering period. Owing to this fact the advantages of a normal frequency curve are obvious, as by its use the normal increase or decrease in the curve for a particular time period may be eliminated and only the abnormalities considered.—*J. B. Kincer.*

THE BIOCLIMATIC LAW.[1]

By Dr. ANDREW D. HOPKINS, Bureau of Entomology.

[Abstract.]

The normal northward and upward advance of the leafing out of trees, the appearance of insects, etc., in spring, and the southward retreat of phenological events, in autumn, have been the subject of observation for more than a century in the United States. Dr. Hopkins has been particularly drawn to the study of phenology by the value of knowing the time of emergence of certain forest insects and of the hessian fly. His studies which led him to examine planting and harvest dates as well as other phenological dates has placed on a firm foundation the *bioclimatic law*.[2] Dr. Hopkins's own statement follows:

Variations in the date of a periodical event from a given norm or constant are a measure, in terms of time, of the intensity of the controlling influences and forces as related (*a*) to geographical position, (*b*) to the season, (*c*) to the inherent tendency of species under the same external influences to vary towards early and late individual responses, and (*d*) to early and late responses of individuals of the same variety under varying local influences. The variation from a constant in the date of an event also measures the intensity of the controlling influences in terms of distance as related to feet of altitude or equivalents in degrees of latitude or longitude.

Studies in the application of these principles show quite conclusively that the responses to the controlling influences and forces are in accordance with natural law, in that (*a*) the time of occurrence of a given periodical event in the seasonal activity, or (*b*) the latitude limits of distribution of an organism, or (*c*) its altitude limits, are determined primarily by geographical position. Therefore, *other things being equal*, the variation between two or more geographical positions bears the same proportion to the distance between them, that 4 days of time bears to 1 degree of latitude, 400 feet of altitude, or 5 degrees of longitude [average only for the whole width of the continent]. * * *

As measured in time the variation from the constants is found to range from one to forty, with a maximum of fifty days at certain points along the Pacific Coast. As measured in altitude the variations are from 100 to 3,000 , with a maximum of 5,000 feet. In these departures the earlier dates and higher altitudes are the result of accelerating influences, and later dates and lower altitudes are due to retarding influences.

In order to gather further facts and evidence on the variations from the constant and also the rate of advance of the spring season, as revealed by periodical phenomena, observations were begun at Brownsville in southeastern Texas and at Palm Beach and Miami, Fla., in February of the present year (1919). These were continued along routes from Brownsville in a general northeastward direction to the northern borders of the States of New York, Vermont, and Maine, and to above the timberline on Mount Washington, from Miami north along the Atlantic coast to Washington and from Palm Beach across the Florida Peninsula to Fort Wayne, then north to Lake City and west to Pensacola, and return to Washington by the way of Birmingham, Ala., Atlanta, Ga., and Charlotte, N. C. These routes involved a travel, principally by rail, by Messrs. Griffith, Craighead, Snyder, and the writer, of over 20,000 miles and the recording of over 20,000 observations. The data accumulated by these investigations has served not only to verify the facts and evidence furnished by the wheat harvest and altitude limit data but has contributed information toward the solving of many other problems of scientific and economic interest, relating to the application of the law in research and practice. * * *

[1] Jour. Wash. Acad. Sci., Jan. 19, 1920, **10**: 34–40.
[2] See MONTHLY WEATHER REVIEW, Suppl. 9, 1918, and *Scientific Monthly* June, 1919, **8**: 496–513.

BAROMETRIC GRADIENT AND EARTHQUAKE FREQUENCY.

By T. TERADA and S. MASUZAWA.

[Abstracted from Proc. of Physico-Math. Soc. of Japan, 3 ser., vol. 1, pp. 343–347, 1919.]

For each of a number of areas surrounding a given epicentral zone, the mean barometric gradient (amount and direction) for each of n successive years is calculated; the mean of the n means is taken, and the departure of each from this general mean found; the product-sum of these departures and the number of quakes originating in the epicentral zone during the corresponding year, divided by the total number of quakes, gives a vector which may be considered in some measure as the most effective deviation of the barometric gradient of that area in causing earthquakes in the particular zone. The mapping of the vectors for each of the areas surrounding the zone throws some light on the general seismic mechanism.

For two epicentral zones of Japan, the data for 1902–1915 show that most of the deviation vectors (pointing toward the high pressure) are nearly perpendicular to the axis of the island, those to the west of a line from Sado to Tokyo being directed more or less toward the Pacific side, and those to the east pointing generally toward the Japan Sea side; the type of surface loading suggested, if applied simultaneously, would be favorable to effect or produce fracture of a fissure located along, or parallel to, this line.—*E. W. W.*

EARTHQUAKE FREQUENCY AND RAINFALL.

In the Tokyo *Asahi* for January 29, 1913, Prof. Omori directed attention to a remarkable coincidence between the frequency of earthquakes as recorded at Tokyo by the seismometer and the total amount of rain and snowfall in northwestern Japan; but was unable to assign a reason for the apparent relationship. According to *Nature* (vol. 91, p. 65, 1913):

The relationship is borne out by statistics covering the whole of the Meiji era—45 years from 1867. The number of earthquakes recorded annually at Tokyo between 1876 and 1909 is found to be practically in

direct ratio to the amount of rain and snowfall at Niigata and Akita, on the Japan sea coast. The curves for earthquake frequency in Japan show that these disturbances gradually increase in number over a period of years, and then undergo a corresponding decline, and in accordance with a recognized principle, destructive earthquakes are most likely to occur in a period of minimum earthquake frequency. Such minima occurred in 1883, 1893, and 1903, and very violent earthquakes took place in 1884 and 1894. These periods, it is noted, corresponded to a conspicuous freedom from rain and snowstorms in the north, while in the years of maximum earthquake frequency at Tokyo, i. e., with no violent shocks, the amount of rain and snow falling in the north was much above the average.

In the Journal of the College of Science, Tokyo Imperial University (vol. xli, Art. 5), Prof. Terada, in a paper devoted mainly to another topic (see *Nature*, vol. 105, pp. 599–600, July 8, 1920), describes the above correlation between earthquake frequency in some districts and precipitation in others as a case of parallelism rather than one of cause and effect; he prefers to attribute both phenomena to barometric changes rather than to associate the instability of the soil with percolation.—*E. W. W.*

ON THE PROPORTIONALITY BETWEEN EARTHQUAKE FREQUENCY AND RAINFALL.

By G. ZEIL.

[Abstract from Comptes Rendus, Paris Academy, t. 171, pp. 117-119, 12 July, 1920.]

Upon comparing a chart of the seismic belts of the globe with a chart of the distribution of rainfall, striking similarities are found. Regions of heaviest rainfall, such as Assam, east coast of Madagascar, Dalmatian coast, east coast of Mindanao, western Norway, etc., are also the most frequently and severely shaken by earthquakes. That this relation is due to sudden readjustments following the accumulation of stress caused by erosion and deposition is confirmed by the fact that the rainy Amazon Valley is almost free from earthquakes, because the heavy forest covering prevents denudation. The restoration of equilibrium in a lithospheric arch previously unloaded by erosion would give rise to what may be termed a centrifugal quake, and an upward movement of the arch; the restoration of equilibrium in a deep basin previously loaded by deposition would give rise to a centripetal quake, and a sinking of the basin; simultaneous restoration of equilibrium in two such regions adjacent to one another would cause an antagonistic quake. Actual tectonic quakes appear to conform to this classification (G. Zeil, "Les mouvements ascensionnels de l'écorce terrestré et les tremblements de terre tectoniques," *Bull. Soc. Géol. de France*).

Discussion.—The above may possibly be a factor in the explanation of the apparent connection between rainfall and earthquakes, but the abstractor desires to point out that the theory upon which G. Zeil bases his views of geodynamics seems to be, as expounded in a series of papers (*Comptes Rendus*, 169, 1406–1408, 1919; 170, 397–399, 597–600, 1920), a somewhat superficial combination of generally recognized geologic facts into a theory which can be attacked at several points. Although rejecting the doctrine of isostasy, Zeil presents views which practically amount to an acceptance of it. The whole ground covered by him has previously been subjected to a truly profound analysis by Chamberlin, Barrell, and others (see, e. g., Barrell, "Strength of the Earth's Crust," *Jour. Geol.*, vols. 22–23; Chamberlin, "Diastrophism and the Formative Processes," *Jour. Geol.*, vols. 21–22; and other recent writers on geodynamics.)—*E. W. Woolard.*

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C. F. TALMAN, Professor in Charge of Library.

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SPECIAL OBSERVATIONS.

SOLAR AND SKY RADIATION MEASUREMENTS DURING JUNE, 1920.

By Herbert H. Kimball, Professor of Meteorology.

(Weather Bureau Solar Radiation Investigations Section, Washington, July 29, 1920.)

For a description of instruments and exposures, and an account of the method of obtaining and reducing the measurements, the reader is referred to this Review for April, 1920, **48**:225.

The monthly means and departures from normal in Table 1 indicate that solar radiation intensities were above normal at all four stations, the excess for air mass 2.0 averaging about 6 per cent.

Table 2 shows an excess in the total radiation received on a horizontal surface at Washington and Madison during the five weeks, May 28 to July 1, inclusive, although at Washington there was a deficiency during the three weeks, June 4 to 24, inclusive. Owing to a broken wire in one of the grids of the callendar pyrheliometer in use at Lincoln it has been necessary to temporarily discontinue the automatic record of solar and sky radiation at that station.

Skylight polarization measurements obtained at Washington on four different days give a maximum of 54 per cent and a mean far the month of 48 per cent. Measurements obtained at Madison on two days give a maximum of 72 per cent and a mean of 70 per cent. These are average values for June for Washington, and above the average for Madison.

Table 1.—*Solar radiation intensities during June, 1920.*

[Gram-calories per minute per square centimeter of normal surface.]

WASHINGTON, D. C.

Date.	Sun's zenith distance: 8 a.m. — 75th meridian time.	77.8°	75.7°	70.7°	60.0°	0.0°	60.0°	70.7°	75.7°	77.8°	Noon. — Local mean solar time.
	Air mass: e.	A. M. 5.0	4.0	3.0	2.0	*1.0	P. M. 2.0	3.0	4.0	5.0	e.
	mm.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	mm.
June 1	13.13					1.33					11.38
2	13.13				0.92						15.11
7	8.48			1.01	1.16	1.27					7.29
14	15.11					1.41					12.24
24	13.61			0.73	0.91	1.10					11.81
25	12.24					1.34	1.01				10.21
26	9.83		0.69	0.83	1.00						7.87
Means			**(0.69)**	**0.86**	**1.00**	**1.29**	**(1.01)**				
Departures			**+0.04**	**+0.10**	**+0.09**	**+0.02**	**+0.02**				

Table 1.—*Solar radiation intensities during June, 1920*—Contd.

MADISON, WIS.

Date.	Sun's zenith distance: 8 a.m. — 75th meridian time.	77.8°	75.7°	70.7°	60.0°	0.0°	60.0°	70.7°	75.7°	77.8°	Noon. — Local mean solar time.
	Air mass: e.	A. M. 5.0	4.0	3.0	2.0	*1.0	P. M. 2.0	3.0	4.0	5.0	e.
	mm.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	mm.
June 2	11.38						1.22				9.14
3	6.76			1.12	1.25	1.39					6.27
8	10.59			1.06	1.21	1.42	1.13	0.92			9.83
16	17.37				1.09						15.11
18	8.81					1.36					8.48
22	11.38					1.30					9.47
24	11.38					1.18					10.21
28	17.37					1.14					18.59
30	14.10		0.82	0.95	1.10	1.34					13.61
Means			**(0.82)**	**1.04**	**1.16**	**1.30**	**(1.18)**	**(0.92)**			
Departures			**−0.05**	**+0.08**	**+0.03**	**±0.00**	**+0.12**	**+0.04**			

LINCOLN, NEBR.

Date.	8 a.m.	5.0	4.0	3.0	2.0	*1.0	2.0	3.0	4.0	5.0	Noon.
June 2	8.18					1.46					5.79
5	7.04			1.06	1.25	1.47	1.19	0.98	0.86	0.74	7.57
8	17.37						1.04				17.37
12	12.24			0.84							14.10
21	9.14					1.45					7.04
23	9.14			0.90	1.13	1.43	1.15	0.95	0.82		7.57
Means				**0.93**	**(1.19)**	**1.45**	**1.13**	**(0.96)**	**(0.84)**	**(0.74)**	
Departures				**+0.01**	**+0.11**	**+0.09**	**+0.03**	**+0.05**	**+0.07**		

SANTA FE, N. MEX.

Date.	8 a.m.	5.0	4.0	3.0	2.0	*1.0	2.0	3.0	4.0	5.0	Noon.
June 4	6.27			1.06							7.29
14	6.76		1.02	1.08	1.27	1.49					5.36
15	5.56		1.06	1.11	1.34	1.55	1.32	1.16	1.01		2.87
16	4.17		1.04	1.20	1.27	1.60					2.87
17	4.37		1.08								3.45
18	5.56			1.15	1.31						5.79
21	4.37			1.30	1.39						2.74
24	5.79					1.59					3.63
28	7.87						1.32	1.14			9.83
29	7.29		1.05	1.14	1.26						7.04
Means			**1.05**	**1.15**	**1.31**	**1.56**	**(1.32)**	**(1.15)**	**(1.01)**		
Departures			**+0.10**	**+0.09**	**+0.08**	**+0.10**	**±0.00**	**−0.01**	**±0.00**		

* Extrapolated.

TABLE 2.—*Total radiation received on a horizontal surface from the sun and sky.*

Week beginning—	Average daily radiation.		Average daily departure for the week.		Excess or deficiency since first of year.	
	Washington.	Madison.	Washington.	Madison.	Washington.	Madison.
	Cal.	*Cal.*	*Cal.*	*Cal.*	*Cal.*	*Cal.*
May 28	673	566	179	77	1,321	182
June 4	454	582	—44	79	1,012	734
11	463	480	—50	—38	665	465
18	446	548	—77	17	126	571
25	620	519	96	—21	801	426

SOLAR RADIATION INTENSITIES IN THE PACIFIC COAST STATES.

By HERBERT H. KIMBALL, Professor of Meteorology.

[Weather Bureau, Washington, D. C., July 26, 1920.]

In the REVIEW for November, 1919, **47**:775, an approximate estimate was made of radiation intensities in the Pacific Coast States, based on the intensities measured at Washington and the difference in surface vapor pressures in the two regions.

A recent trip through California and Oregon afforded an opportunity to measure intensities on the Pacific coast at La Jolla, Calif., and at several interior points the coordinates of which are as follows:

Station.	Latitude.	Longitude.	Elevation above sea level.	
	° ′	° ′	*Feet.*	*Meters.*
La Jolla, Calif	32 50 N.	117 15 W.	100	30
Pomona, Calif	34 03 N.	117 45 W.	870	265
Fresno, Calif	36 43 N.	119 49 W.	360	110
Red Bluff, Calif	40 10 N.	122 15 W.	360	110
Medford, Oreg	42 20 N.	122 49 W.	1,425	468

The measurements were made with Smithsonian silver disk pyrheliometer No. 1, usually from the roof of the hotel at which I happened to be stopping; but at Fresno and also at Red Bluff, Calif., the instrument was exposed on the roof of the building in which the Weather Bureau office is located.

Table 1 gives a summary of the pyrheliometric measurements. Table 2 gives the surface vapor pressure at the Weather Bureau station nearest to the point of observation, on days when pyrheliometric measurements were obtained. San Diego observations undoubtedly represent sufficiently well the hygrometric conditions at La Jolla, which is only about 16 miles distant along the coast. Those for Los Angeles may not approximate so closely the conditions at Pomona, which is farther inland, and presumably drier. In February, however, the difference between the two stations probably is not great.

Comparing the data of Tables 1 and 2 with corresponding data for February and March given in the REVIEW for April, 1920, page 226, Table 1, it will be seen that while vapor pressures are markedly higher than at Washington, Madison, and Lincoln, the radiation intensities are considerably higher than corresponding normal values for Washington, slightly higher than for Lincoln, and slightly lower than the Madison normals. Furthermore, the intensities show much less change from day to day and from place to place notwithstanding considerable changes in elevation, than do measurements at the stations east of the Rocky Mountains. Apparently, therefore, solar radiation intensities on the coast of southern California, as well as in the interior valleys of California and southern Oregon, are comparable with intensities in the Central and Southern Plains States, at least in the late winter and early spring months.

TABLE 1.—*Solar radiation intensity measurements in California and Oregon during February–April, 1920.*

[Gram calories per minute per square centimeter of normal surface.]

Date.	Sun's zenith distance.										
	0.0°	48.3°	60.0°	66.5°	70.7°	73.6°	75.7°	77.4°	78.7°	79.8°	80.7°
	Air mass.										
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
POMONA, CALIF.											
	cal.	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*
Feb. 26a	1.59	1.45	1.33	1.23	1.13	1.05	0.98	0.91	0.85	0.80	......
26p	......	1.43	1.21	1.03	0.90	0.80	0.72	0.67	......	......	......
28a	......	1.37	......	......	......	......	......	......	......	......	......
LA JOLLA, CALIF.											
Mar. 2p	1.55	1.41	1.29	1.18	1.10	1.03	0.96	0.91	......	......	......
3p	1.51	1.41	1.32	1.24	1.17	1.10	1.04	0.98	......	......	......
4 a. m	1.56	1.45	1.34	1.25	1.16	1.08	1.02	0.96	......	......	......
4 p. m	......	1.45	1.34	1.25	1.16	1.08	1.02	0.96	0.90	0.86	0.81
FRESNO, CALIF.											
Mar. 14a	1.52	1.42	1.34	1.26	1.18	1.11	1.05	0.98	0.91	0.85	......
14p	1.52	1.42	1.33	1.24	1.15	1.07	1.00	0.93	0.87	0.82	......
RED BLUFF, CALIF.											
Mar. 23a	1.50	1.41	1.32	1.23	1.15	1.07	......	......	......	......	......
25a	......	1.40	......	......	......	......	......	......	......	......	......
MEDFORD, OREG.											
Mar. 28a	1.55	1.42	1.31	1.21	1.12	1.05	0.98	......	......	......	......
29a	......	......	1.15	......	......	......	......	......	......	......	......
29p	1.47	1.37	1.27	1.18	1.10	1.02	0.96	0.91	0.86	0.82	......
30a	......	......	......	......	0.90	......	......	......	......	......	......
Apr. 5p	......	1.40	......	1.22	1.14	......	......	......	......	......	......
Means	1.53	1.42	1.29	1.21	1.11	1.04	0.97	0.91	0.88	0.83	......

TABLE 2.—*Surface-water vapor pressures.*

Station.	Date, 1920.	Time (120th meridian).		
		5 a. m.	Noon.	5 p. m.
		mm.	*mm.*	*mm.*
Los Angeles, Calif	Feb. 26	7.04	5.56	7.57
	Feb. 28	7.04	9.14	8.81
San Diego, Calif	Mar. 2	....	8.81	8.48
	Mar. 3	7.87	8.18	7.87
	Mar. 4	6.27	8.18	9.14
Fresno, Calif	Mar. 14	5.16	4.75	3.99
Red Bluff, Calif	Mar. 23	6.27	6.76	5.16
	Mar. 24	6.76	4.75	5.36
Medford, Oreg	Mar. 28	6.02	....	....
	Mar. 29	4.95	....	5.56
	Mar. 30	3.99	....	....
	Apr. 5	....	....	6.50

MEASUREMENTS OF THE SOLAR CONSTANT OF RADIATION AT CALAMA, CHILE.

By C. G. ABBOT, Assist. Secretary, Smithsonian Institution, Washington, D. C.

In continuation of preceding publications, I give in the following table the results obtained at Calama, Chile, in May, 1920, for the solar constant of radiation. The reader is referred to this REVIEW for February, August, and September, 1919, for statements of the arrangement and meaning of the table.

Date.	Solar const.	Method.	Grade	Transmission coefficient at 0.5 micron.	Humidity.			Remarks.
					ρ/ρSC.	V. P.	Rel. hum.	
1920 A. M.	cal.					cm.	Per cent.	
May 1	1.933	$M_{1.40}$	S−	0.859	0.610	0.41	25	Cirri all over sky prevented earlier observations.
2	1.950	M_3	S	.870	.608	.20	21	Wind carrying dust at times. Possibly some Chuqui smoke.
	1.947	M_2						
	1.948	W. M.						
3	1.983	E_0	VG+	.853	.600	.18	18	
	1.955	M_3						
	1.962	M_2						
	1.950	$M_{1.5}$						
	1.961	W. M.						
4	1.953	M_3	S	.865	.560	.17	14	
	1.961	M_2						
	1.954	$M_{1.5}$						
	1.957	W. M.						
5	1.938	M_2	U+	.861	.644	.19	17	Smoke from Chuqui near sun.
6	1.932	M_3	U+	.872	.578	.17	19	Cirri in west. Some smoke from Chuqui.
	1.958	M_2						
	1.949	W. M.						
7	1.945	M_3	G+	.866	.549	.22	22	Some cirri in northwest. Probably some Chuqui smoke.
	1.964	M_2						
	1.937	$M_{1.5}$						
	1.952	W. M.						
P. M. 8	1.950	M_3	S−	.872	.615	.32	19	Some haze and dust. Chuqui smoke near sun.
	1.961	$M_{2.16}$						
	1.957	W. M.						
A. M. 9	1.900	$M_{2.28}$	S−	.864	.541	.22	22	Some scattered cirri in southwest rapidly vanishing.
	1.932	M_2						
	1.921	W. M.						
10	1.968	M_2	U+	.863	.533	.23	21	Smoke from Chuqui near sun.
	1.907	$M_{1.5}$						
	1.938	W. M.						
11	1.969	E_0	E−	.870	.688	.15	15	Gusts of wind carried some dust at times during early observations.
	1.972	M_3						
	1.970	M_2						
	1.961	$M_{1.5}$						
	1.968	W. M.						
12	1.950	M_3	S	.870	.612	.16	13	Smoke from Chuqui below sun in M_3.
	1.950	M_2						
	1.965	$M_{1.5}$						
	1.952	W. M.						
13	1.942	$M_{2.5}$	S−	.863	.631	.12	10	Cirri low in east moving rapidly away prevented M_3. 9:00 Cirri appearing in west. $M_{1.5}$ prevented by smoke coming from west.
	1.961	$M_{2.5}$						
	1.955	W. M.						
14	1.974	E_0	P+	.823	.488	.18	19	Cirri in west and south.
	1.920	$M_{2.5}$						Chuqui smoke in east mostly below sun, apparently in early bolograph.
	1.952	M_2						
	1.937	W. M.						
16	1.960	M_3	S	.869	.522	.23	25	
	1.956	M_2						
	1.955	$M_{2.20}$						
	1.957	W. M.						
17	1.945	M_2	U+	.866	.668	.15	19	Chuqui smoke prevented other observations.
1920 A. M.	cal.					cm.	Per cent.	
19	1.958	$M_{2.5}$	S	.852	.448	.27	32	Cirro cumuli in east preventing. M_3. Chuqui smoke prevented long method. Cumuli in north.
	1.960	M_2						
	1.959	W. M.						
20	1.966	E_0	VG+	.874	.633	.23	30	
	1.966	M_3						
	1.947	$M_{2.5}$						
	1.961	W. M.						
21	1.922	M_3	S−	.868	.693	.10	12	Probably Chuqui smoke below sun.
	1.939	$M_{2.5}$						
	1.930	W. M.						
22	1.907	M_3	S−	.864	.603	.12	16	Chuqui smoke below sun.
	1.931	$M_{2.5}$						
	1.946	M_2						
	1.934	W. M.						
23	1.918	M_3	S−	.873	.683	.10	12	Slight streakiness in east, perhaps Chuqui smoke. Cirri appearing in west at M_3.
	1.937	M_2						
	1.947	$M_{1.5}$						
	1.939	W. M.						
24	1.930	$M_{1.67}$	S−	.862	.654	.20	16	Some cirri in east.
	1.946	$M_{1.5}$						
	1.938	W. M.						
25	1.960	M_2	S	.865	.598	.18	21	Very thin cirri scattered about much of sky. Earlier observations prevented by smoke and clouds.
	1.966	$M_{1.91}$						
	1.963	W. M.						
26	1.895	M_3	U+	.865	.571	.12	19	Distant cirri in northeast Chuqui smoke interferred with M_3 and prevented $M_{2.5}$.
	1.921	M_2						
	1.914	W. M.						
27	1.964	M_3	S	.875	.711	.11	13	Distant cirri in east.
	1.954	$M_{2.5}$						
	1.957	M_2						
	1.959	W. M.						
28	1.952	M_3	S	.871	.671	.10	12	Very distant cirri in northwest. Smoke from Chuqui and from lime kiln may have interferred with M_3.
	1.950	$M_{2.5}$						
	1.946	M_2						
	1.948	W. M.						
29	1.919	$M_{2.5}$	S−	.867	.706	.08	8	Cirri in southeast. Chuqui smoke prevented long method and M_3m and probably interferred with $M_{2.5}$ and M_2.
	1.947	M_2						
	1.940	W. M.						
30	2.008	E_0	VG	.862	.747	.07	9	Strong gusty wind from east raising some dust.
	1.995	M_3						
	1.969	$M_{2.5}$						
	1.967	M_2						
	1.977	W. M.						
31	1.946	M_2	S−	.872	.768	.07	9	Considerable Chuqui smoke in east preventing long method and M_3. Probably affected M_2.

WEATHER OF THE MONTH.

WEATHER OF NORTH AMERICA AND ADJACENT OCEANS.

NORTH PACIFIC OCEAN.

By F. G. TINGLEY.

Reports at hand indicate that weather conditions over the North Pacific Ocean during the month of June as a whole closely approximated the normal. However, for the first several days the activity noted in May continued, with pressure generally below normal over the eastern half of the ocean, where the North Pacific anticyclone is usually well established at this season. At this time, also, reports from vessels in Asiatic waters indicated the existence of a typhoon. There was a disturbance with a well-defined center to the east of Manila on the 1st which moved to the northeastward during subsequent days, traversing the island of Nippon during the 4th and 5th.

On June 6, the American S. S. *City of Berkeley*, Capt. Alex. Watson, from Honolulu for Yokohama (in latitude 34° 32′ N., longitude 153° 05′ E., at noon of the 6th), came under the influence of this depression. Capt. Watson reports as follows:

"June 6–7, weather showed every sign of a typhoon having occurred. Barometer fairly low; clouds unusually heavy; W.–NW. swell, changing to W.–SW. No gales or heavy wind at ship."

This depression can be traced as far as the Gulf of Alaska, which it reached about the 15th, but apparently none of the reports that have been received is from a vessel that was near the center.

After the 6th, moderately high pressure covered the central and eastern portions of the ocean, the crest rising above the normal maximum of 30.25 inches on several days during the last decade.

A result of this was to freshen the trades between the mainland and the Hawaiian Islands, affecting a number of ships on the route between San Francisco and Honolulu. One vessel, the Dutch S. S. *Batoe*, reports as follows:

"Gale began on the 18th. Lowest barometer 29.94 inches at 8 a. m. of the 20th, latitude 37° 24′ N., longitude 123° 34′ W. End on the 20th. Highest force of wind, 9; shifts, none."

NORTH ATLANTIC OCEAN.

By F. A. YOUNG.

The average pressure for the month at land stations on the coasts of the Atlantic Ocean, did not as a rule, vary greatly from the normal; except that it was somewhat lower than usual on the east coast of Newfoundland and higher in northern Scotland.

Ordinarily there are fewer days in June in which winds of gale force are encountered over the ocean than in any other month, and the month under discussion was no exception to the general rule over the ocean as a whole, although in three 5-degree squares between the forty-fifth and fiftieth parallels and the twentieth and thirty-fifth meridians, gales were reported on three days, which is slightly above the normal.

According to the reports received, there were about the usual number of days with fog on the Banks of Newfoundland and the American coast, while it was much more frequent off the British coast and in the Azores.

On the 1st there was a LOW with limited storm area central about 300 miles east of St. Johns, Newfoundland, as shown on Chart IX. The storm log from the American S. S. *Hanover* is as follows: "Gale began May 31. Lowest barometric reading 29.59 inches at 2 a. m. on June 1; position 41° 10′ N., 46° 30′ W. End of gale on the 1st. Highest force of wind, 9; shifts of wind near time of lowest barometer, N. to NW." This disturbance had moved slowly eastward by the 2d (see Chart X), and on that date a few reports were received from vessels in the easterly quadrants denoting southerly gales. The observer on the American S. S. *Western Star* reports: "Gale began on the 1st. Lowest barometer 29.60 inches at 9 a. m. on the 1st; position 48° 47′ N., 36° 15′ W. End of gale on the 2d. Highest force of wind 8; shifts SSW. to SSE."

From the 3d to the 5th no gales were reported, and fog occurred on all three days off the European coast, and on the 3d in the vicinity of Halifax, N. S. On the 6th, two vessels about 200 miles east of the Virginia Capes reported southerly gales of about 50 miles an hour, with moderate weather over the rest of the ocean, and fog off the Nantucket shoals and over the southern steamer routes, near the fiftieth meridian. From the 7th to the 10th there was another period of nearly normal conditions, with fog over the Banks of Newfoundland on all four days, and off the coast of France on the 7th.

On the 11th there was a well-developed LOW central near latitude 48° N., longitude, 15° W., with gales between the center and the 23d meridian, as shown on Chart XI. The storm log from the American S. S. *Saguache* is as follows: "Gale began on the 10th. Lowest barometer 29.17 inches on the 11th; position 49° 54′ N., 14° 42′ W. End of gale on the 12th. Highest force of wind 9; shifts of wind SE–N–NW." On the 12th the Belgian S. S. *Sierra Madre* encountered a moderate westerly gale while about 500 miles east of Bermuda. The storm log states: "Gale began on the 12th. Lowest barometer 29.80 inches at 5 a. m. on the 12th; position 33° 35′ N., 53° 40′ W. End of gale on the 13th. Highest force 8; shifts of wind SW–W." On the 12th and 13th fog was reported over the steamer lanes between the fortieth and fiftieth meridians. From the 14th to the 16th moderate winds were the rule, with fog at the Azores and over the western part of the steamer lanes on the 14th and 15th, and in the vicinity of the British Isles on the 16th.

The American S. S. *Abbeville* ran into a southwesterly gale on the 17th while a short distance north of Bermuda, as shown by the storm log. Gale began on the 16th. Lowest barometer 29.70 inches, at midnight of the 16th; position 36° 07′ N., 64° 30′ W. End of gale on the 18th. Highest force of wind 8; shifts of wind, steady. On the 19th there was a disturbance of some force and limited area over the eastern part of the steamer lanes; the storm log of the British S. S. *Stanmore* is as follows: "Gale began on the 19th. Lowest barometer 29.20 inches at 10 a. m. on the 19th; position 49° 39′ N., 26° 00′ W. End of gale on the 20th. Highest force of wind 10; shifts of winds SSW.–NW. by W." This LOW drifted slowly eastward, and on the 20th the center was near latitude 51° N., longitude 20° W. The observer on the British S. S. *Penmorvah* states in the storm log: "Gale

began on the 19th. Lowest barometer 29.36 inches at 4 p. m. on the 19th; position 50° 54' N., 20° 44' W. End of gale on the 20th. Highest force of wind 10; shifts of wind SW.-W.-NW.

During the next 24 hours this depression remained nearly stationary, gradually filling in, as on the 21st. The American S. S. *Munra* was the only vessel to report winds of gale force. Her storm log is as follows: "Gale began on the 19th. Lowest barometer 29.59 inches at 4 a. m. on the 19th; position 48° 16' N., 18° 00' W. End of gale on the 21st. Highest force of wind, 8; shifts of wind, SW.-W." From the 22d to the 27th moderate conditions prevailed with the Azores HIGH well developed during the greater part of the period. On the 22d and 23d fog occurred off the Banks of Newfoundland and from the 24th to the 27th over the middle section of the southern steamer routes. On the 28th there was a LOW of considerable extent central somewhere near latitude 55° N., longitude 22° W. (see Chart XII); it was impossible, however, to locate it accurately on account of lack of observations up to date. The storm log from the Danish S. S. *Arkansas* is as follows: "Gale began on the 27th. Lowest barometer 29.40 inches at midnight on the 27th; position, 53° 30' N., 28° 55' W. End of gale on the 28th. Highest force of wind 10; shifts of wind W.-WNW." This disturbance apparently moved but little during the next 24 hours, decreasing in intensity, and on the 30th only light to moderate winds were reported, with fog in mid-ocean.

NOTES ON WEATHER IN OTHER PARTS OF THE WORLD.

British Isles.—"* * * conspicuous events were the frequent thunderstorms which occurred between the 10th and 20th, and the almost entire absence of any very hot days.

"For the first time in 1920, the total monthly rainfall was generally deficient over the British Isles, exceeding the average only in small isolated areas, particularly in the south of England and Wales. * * *

"The general rainfall expressed as a percentage of the average was: England and Wales, 99; Scotland, 65; Ireland, 78. * * *

"In London (Camden Square) the mean temperature was 61.5° F., or 1.3° F. above the average. * * *"[1]

Mediterranean region.—"Very high temperatures were experienced [during the middle and latter half of the month]. * * *"[1]

India.—"In India the southwest monsoon set in on June 2 in Malabar and penetrated inland a few days later. It was weak at first in most parts (except Burma, Assam, and Central India)."[1]

Africa.—"The monsoon appears to have set in vigorously in Africa, for sudden rises of the Nile at Roseires and Mongalla have brought the water to its normal level."[1]

Australia.—"In Australia copious rains have continued to fall, and there is now a prospect of abundant herbage for stock. In the possible wheat belt of New South Wales the rain has enabled an unusually large acreage to be brought into cultivation. At the close of the month snow fell for the first time on record at Albany, in the interior of West Australia (latitude 35° south), probably in the rear of an Antarctic reversed V depression."[1]

[1] The Meteorological Magazine, July, 1920, pp. 133, 136.

DETAILS OF THE WEATHER OF THE MONTH IN THE UNITED STATES.

CYCLONES AND ANTICYCLONES.

By R. HANSON WEIGHTMAN, Meteorologist.

Cyclones.—Alberta LOWS were by far the most numerous and secondaries were infrequent. The table shows the number of LOWS by types.

LOWS.

	Alberta.	North Pacific.	South Pacific.	Northern Rocky Mountain.	Colorado.	Texas.	East Gulf.	South Atlantic.	Central.	Total.
June, 1920	7.0	1.0	0.0	1.0	1.0	0.0	1.0	1.0	1.0	13.0
Average number 1892-1912	3.3	0.8	0.4	0.8	1.2	0.4	0.2	0.3	1.1	8.4

Anticyclones.—The number of HIGHS was slightly below the average. The number of HIGHS by types is shown in the table.

HIGHS.

	North Pacific.	South Pacific.	Alberta.	Plateau and Rocky Mountain region.	Hudson Bay.	Total.
June, 1920	2.0	0.0	3.0	0.0	0.0	5.0
Average number 1892-1912	1.6	0.6	1.9	0.9	0.5	5.5

THE WEATHER ELEMENTS.

By P. C. DAY, Climatologist and Chief of Division.

[Weather Bureau, Washington, Aug. 2, 1920.]

PRESSURE AND WINDS.

The pressure during June exhibited the stagnant condition usual to the warmer months of the year, and the cyclonic and anticyclonic movements were in the main but poorly defined (See Charts II and III). As is usual in June, pressure was moderately high over the southeastern districts and in the far Northwest (See Chart VII), but this distribution varied materially during the month. The first week had rather low pressure with rain over much of the East and Southeast, particularly near the Atlantic coast, high pressure prevailing at the same time in the Central Valleys and far western districts. The high pressure drifted slowly into the more eastern States overspreading the Southeast during the latter part of the first and the early part of the second decades. At the same time there was a general reduction in pressure over the interior portions of the country where temperatures had very generally risen to or above the normal for the season.

During the latter part of the second decade pressure increased in the far Northwest and there was a change to lower barometer readings over the Gulf and Atlantic coast districts with local storm areas and very general precipitation in the districts from the Mississippi Valley eastward. During the greater part of the last decade the HIGH over the North Pacific coast was maintained but

with somewhat diminished size, and the usual summer HIGH over the southeastern States was gradually re-established, so that at the end of the month pressure had assumed the usual warm season type, moderately high over the relatively cool, coast districts and low over the heated interior.

Southerly winds were mostly in evidence during the month from the Great Plains eastward, while from the Rocky Mountains westward to the Pacific they were largely from the west, modified greatly, however, by local topography.

TEMPERATURE.

The month was without unusual temperature extremes, as a whole.

The first week was generally cool in all parts of the country, save from the middle and southern Plateau regions westward to the Pacific. A pronounced change occurred during the second week and this period had temperatures decidedly higher than normal over all portions of the country from the Rocky Mountains eastward, except in the southern Plains and West Gulf regions, where cool weather for the season continued. In the lower Missouri and upper Mississippi Valleys the week was from 6° to 12° warmer than the average. West of the Rocky Mountains the weather continued cool.

The third week of the month was distinctly cool, on the average, in all parts of the country, save in the extreme southern States and over California and portions of the adjoining States. During the latter part of the month moderate rises to temperatures above normal were experienced over considerable areas from western Texas and eastern New Mexico northeastward to the Great Plains.

On the whole (as shown on Chart IV) the average temperature for the month showed no marked departure from the normal.

The highest temperatures of the month were experienced over the northeastern States on the 1st and 2d where a maximum temperature of 100° F. was recorded in New England. Over the remaining districts east of the Rocky Mountains, the highest temperatures were observed from the 10th to 15th, except locally the 16th or 17th, or later dates. In the Rocky Mountain region the highest temperatures were generally observed about the 8th, while to the westward they occurred from the 18th to 22d when some of the highest temperatures ever experienced in June were reported. In the Great Valley of California, the intense heat caused local injury to fruit, particularly grapes, which were badly sunburned.

The lowest temperatures of the month occurred very generally during the first few days and almost wholly within the first week, the principal exception being over portions of the Southwest where they were delayed until the 20th or later.

Freezing temperatures were reported very generally over the northern tier of States, and at exposed points throughout the mountain States. A temperature as low as 10° F. was observed in Wyoming, and readings below 20° were quite common in other mountain districts. No previous low records were broken, however, and on account of the generally backward condition of vegetation in these districts, no widespread frost damage occurred.

PRECIPITATION.

The first week of the month brought generous and, in some cases, heavy rains over much of the territory extending from the West Gulf States northeastward to southern New England, and more or less liberal amounts were received in most other districts to eastward of the Mississippi River, in portions of the Dakotas, the Southern Plains, and the North Pacific Coast. The rainfall along the coast of northern California was unusually heavy for the period of the year, and brought great relief from the dry conditions that had existed for so long in that region.

During the second week the rain fell in the more northern districts, as a rule, although fairly good rains were reported in portions of western Texas and eastern New Mexico, and rather heavy falls for the season were again received in the extreme Northwest.

Rains were well distributed during the third week over most southern districts from the Great Plains eastward, except in portions of Georgia and Florida, and along the Atlantic coast from the Carolinas northward, in the Appalachian Mountains, the Great Lake region, and in the upper Missouri Valley. During this week but little rain fell over the central corn belt States and there was little or none over practically all the country from the eastern foothills of the Rockies to the Pacific.

The last week of the month brought sufficient rains over the areas drained by the upper Mississippi and northern and eastern tributaries of the Missouri, also in the southern Rocky Mountains and over much of Texas and the immediate Gulf and south Atlantic coasts. In the more central districts from the middle Mississippi Valley eastward to the Atlantic coast, only small areas had appreciable rain, and it was lacking entirely over considerable portions of the cotton, corn, and winter wheat sections. West of the Rockies there was beneficial rain in a few isolated districts only.

The total precipitation for the month showed a considerable deficiency, when compared with the normal, over the middle Plains and thence eastward to the lower Ohio Valley, and in the extreme southeastern States. In portions of Illinois and surrounding States there was little precipitation after the first week and at a few points the precipitation was the least ever recorded in June. From the Dakotas eastward to New England, and over the upper Ohio, and the Middle Atlantic States the precipitation was in many cases well above the normal; in fact, portions of southern New England had, with possibly one or two exceptions, the greatest rainfall for June in fifty years or more.

The southern States from Alabama westward had monthly amounts slightly above normal and similar conditions prevailed along the Pacific coast and in Colorado.

As is frequently the case in summer, the distribution of precipitation was quite irregular, due largely to heavy thunderstorms over small areas. Some of the most prominent are noted in Minnesota, South Dakota, and Texas, where the totals ranged from more than 10 inches to less than 1 inch. Also in the western mountain and Pacific coast States, where local amounts ranged from none or a trace to 6 or 8 inches and even 12 inches or more.

RELATIVE HUMIDITY.

Taking the country as a whole, the relative humidity was below normal generally, but especially in the East Gulf and South Atlantic States and the middle Mississippi Valley. Small areas of pronounced excess, however, occurred in South Dakota and in portions of Arizona, New Mexico, and western Texas.

SEVERE STORMS.

Tornadoes were relatively infrequent. Seven were reported, as follows:

Houghton, Mich., 10th: A small tornado passed within 10 miles of the station. No loss of life, but much damage to growing timber.

Greenville, S. C., 14th: Small tornado near town; slight property loss.

Staten Island, New York City, 16th: A small tornado "swept over the lower end of Staten Island and left a trail of destruction in its wake." Pictures in the New York Evening Post, June 26, 1920, show some of the frame buildings destroyed.

Charlotte, N. C., 20th: Tornado near town caused damage estimated at $30,000. (See pp. 351–352, above.)

Peoria, Ill., 22d: Small tornado 5 miles north of station; no material damage.

Cheyenne, Wyo., 24th: Tornado near Hillsdale, about 18 miles distant from Cheyenne, unusual for that section, but without large damage. (See p. 352, above.)

Rapid City, S. Dak., 29th: Destructive tornado 5 miles west of city, but without large property loss.

A severe storm on June 8 was reported from North Dakota and Minnesota:

St. Paul, Minn., June 9: At least two persons were killed, thirty or more injured, and heavy property damage resulted from a severe wind and electrical storm which swept northern Minnesota and parts of eastern North Dakota last night, according to reports received here early to-day.

* * * * *

Several buildings, including a grain elevator, were destroyed and several persons hurt, but no one was killed.

* * * * *

Breckenridge, Minn., June 9: Fifteen persons were injured, seven seriously, when four coaches of Northern Pacific passenger train No. 156 were blown from the track last night near Foxholme. A score of others received minor hurts. * * *

At Gardner, N. Dak., several cars of a Great Northern freight train were swept from the track and two members of the crew were injured, telegraph reports said.[1]

On the afternoon of June 19 a thunderstorm with a severe squall swept across the region between Washington, D. C., and Rockville, Md. A child was killed in Chevy Chase by a falling tree. A great many trees, some exceeding even a foot in diameter, were broken off or uprooted.

[1] Washington Evening Star, June 9, 1920.

STORMS AND WARNINGS—WEATHER AND CROPS.

STORMS AND WEATHER WARNINGS.

By EDWARD H. BOWIE, Supervising Forecaster.

[Washington, July 23, 1920.]

Washington forecast district.—There were no unusual happenings in the Washington forecast district during the current month. Frost warnings were issued the morning of the 3d for upper Michigan.

Northeast storm warnings were ordered the morning of the 5th for the Atlantic coast at and between Block Island, R. I., and Portland, Me., at which time a secondary disturbance was developing over New Jersey. This disturbance gathered intensity during the 5th, and during the night of this day it caused strong easterly winds and gales off the eastern coast of New England. Storm warnings were not again ordered until the evening of the 15th, and then for western Lake Superior when a disturbance, central over Iowa, showed indications of an increase in intensity and an eastward movement. On the 16th, when the center of this disturbance was over northeastern Iowa, the display of warnings was extended to eastern Lake Superior, Lake Michigan, and northern Lake Huron. The disturbance passed eastward over the Great Lakes on the 16th and 17th, and it was attended by strong winds and moderate gales on these dates. This disturbance approached the north Atlantic coast during the night of the 17th, and the afternoon of that day northwest storm warnings were displayed at and between Cape Henry, Va., and Portland, Me. The highest winds reported on the Atlantic coast in connection with this storm were 48 miles per hour at Block Island and 46 miles per hour at Nantucket. On the evening of the 20th southwest storm warnings were displayed on Lakes Erie and Ontario, and southeast storm warnings on the Atlantic coast at and between Delaware Breakwater and Portland, Me. At this time a disturbance was central over northern Ohio, increasing in intensity and moving northeastward. It was unattended, however, by winds of gale force.

WARNINGS FROM OTHER DISTRICTS.

Chicago forecast district.—No general warnings of any kind were issued during the month. Frost warnings, however, were sent to the Dakotas, Montana, Wyoming, and western Nebraska on the morning of the 1st, and these were verified over most of Wyoming and a portion of Montana. The temperature did not fall to a sufficiently low point for the occurrence of frost in the States farther east.

The cranberry marshes of Wisconsin were unusually free from frost during the month, June 3 being the only day upon which critical temperatures occurred. Frost was reported on that morning from three of the four cranberry marsh stations. The minimum temperature in the bogs ranged from 28° to 30°. Warnings were telegraphed to the growers the previous day, June 2, at 3 p. m.

From time to time forecasts were made in a general way of important changes in temperature, and were well verified. These were published in the daily weather map issued at the Chicago station and also in the Corn and Wheat Region bulletin published at Chicago, and included in the summaries telegraphed daily to the various corn and wheat region centers.—*H. J. Cox.*

New Orleans Forecast District.—There were no noteworthy departures from normal June weather during the month just ended. No storm warnings were issued or needed. Small craft warnings were displayed on the Texas Coast on the 19th.—*R. A. Dyke.*

Denver Forecast District.—No important storms crossed the district during the month, and no frost or freezing temperature warnings were issued, except for high districts in Utah on one date.

Fire-weather warnings were issued on a few dates for the greater part of the district. The highest velocities reported were 48 miles from the SW. at Salt Lake City and 48 miles from the S. at Modena on the 10th. Advices of fresh to strong westerly winds were issued for the greater part of the district, including Utah, on the 9th.—*Frederick W. Brist.*

San Francisco Forest District.—Small-craft warnings were displayed on the 6th, 10th, 22d, and 26th at different

seaports along the coast and they were generally verified. Warnings for heavy frost were sent to southeastern Idaho and northern Nevada on the 1st, which were verified in southeastern Idaho, but not in northern Nevada; and warnings of light frost were issued for eastern Oregon on the 5th and 23d, and both were verified. Fire-weather warnings were issued for California on the 1st and 24th and for northern California on the 18th. These were justified and it is believed did much good.—*E. A. Beals.*

FLOODS DURING JUNE, 1920.

By ALFRED J. HENRY, Meteorologist.

At the close of May the Mississippi below Arkansas City, Ark., the Red, Ouachita and Atchafalaya of Louisiana, the Tallahatchie of Mississippi, the White of Arkansas, the Rio Grande in New Mexico, the lower Trinity of Texas and a few others were in flood. These streams passed below the flood stage during the month (see Table I).

A report on the Mississippi flood in the New Orleans district will be found below; see also this Review, p. 366.

The snow flood in the Rio Grande was unusually severe in New Mexico between Albuquerque and Socorro. The Santa Fe Railroad, which parallels the river in this section, suffered numerous washouts and other interruption to traffic. Considerable damage was also done by overflow water at various places in the stretch above mentioned. Floods also prevailed in the San Juan basin in northwestern New Mexico, and in other tributaries of the Colorado in western Colorado. The crest of the flood on the Colorado passed Yuma, Ariz., on the 8th at a stage of 30.5 feet.

The annual rise in the Columbia, which is also due to melting snow, was one of the least in many years by reason of deficient snowfall.

Torrential rains in central Montana on the 5th caused a flood wave of water from the adjacent canyons to descend upon Lewistown, Fergus County, on the evening and night of the 5th. Loss to business properties, residences, and railroads in the city will reach close to $150,000.

FLOODS IN THE MISSISSIPPI RIVER AND TRIBUTARIES BELOW VICKSBURG MISS., EXCEPT THE UPPER RED RIVER.

The flood in the lower Mississippi River, while it has not equaled previous floods in volume, has been of longer duration than any flood since 1908.

Number of days above present flood stage.

Station.	Year.					Flood stage.
	1903	1908	1912	1913	1920	
						Feet.
Natbhez	54	104	63	37	68	46
Baton Rouge	65	111	69	41	74	35
Donaldsonville	66	107	66	37	71	28
New Orleans	62	95	60	37	68	18
Simmesport		87	69	39	70	41
Melville	45	98	81	48	81	37

Warnings issued in March and April have been discussed in flood warning reports for those months.

There were two distinct floods. The first flood crested generally during the latter part of April. The following warning was distributed to all interests, May 3, 1920:

"The Mississippi River below Vicksburg and the Atchafalaya will change very little or fall slowly until between May 8 and 12, when another rise will set in. Water now in sight indicates between 50.5 and 51.5 at Natchez, May 20 to 24; between 39.2 and 40.2 at Baton Rouge, 35.0 to 36.0 at Plaquemine, 30.5 to 31.5 at Donaldsonville, and 18.7 to 19.6 (depending on the winds) at New Orleans, 43.8 to 44.8 at Simmesport, and 40.6 to 41.6 at Melville, May 25 to 28".

The stages changed very little during the first eight days of May, and the following warning was issued May 8:

"The Mississippi River below Vicksburg and the Atchafalaya will change very little for a few days, when a rise will set in. Water now in sight indicates between 51.0 an 52.0 at Natchez, May 20 to 24; between 40.6 and 41.6 at Baton Rouge, 36.4 to 37.2 at Plaquemine, 32.0 to 32.8 at Donaldsonville, 20.0 to 20.6 at New Orleans (depending upon the winds), 46.0 to 46.5 at Simmesport, and 42.5 to 43.0 at Melville, May 25 to 28."

The rivers continued to rise and crest stages occurred as follows, verifying the warnings as to stages and time of occurrence:

Station.	Stage.	Dates of occurrence.
Natchez	51.2	May 18.[1]
Baton Rouge	41.5	May 22.[1]
Plaquemine	37.2	May 22.
Donaldsonville	32.6	May 18.[1]
New Orleans	20.4	May 17, 18.
Simmesport	46.7	May 21.[1]
Melville	42.5	May 20.[1]

[1] And other dates.

The warnings caused levees to be strengthened and carefully watched to prevent breaks, and live stock and perishable goods subject to damage were moved to places of safety.

The following advisory flood warning was issued May 24, 1920:

"The Mississippi River below Vicksburg and the Atchafalaya will change very little except there will be a slight fall at Natchez. High water will continue until after the middle of June."

Only two crevasses occurred, both on the Mississippi River below New Orleans. On April 17, 1920, the batture and levee on the right bank below Buras, 50 miles below New Orleans, slid into the river and caused a crevasse which threatened considerable damage. Prompt action on the part of the engineers enabled them to close the break within a week and no great damage resulted.

May 27, 1920, a crevasse occurred in the levee on the left bank of the Mississippi River, 16 miles below New Orleans. The crevasse was closed May 30, and no serious damage resulted.

Back water from the Mississippi River into the Red, Ouachita, and Little Black Rivers caused damaging overflows in Avoyelles, Catahoula, Concordia and Tensas Parishes, La.

Floods prevailed in the Red River below Shreveport from May 29 to June 6; in the Ouachita, flood stages reached in May continued at Monroe until June 12. The Atchafalaya was also in flood at Simmesport and Melville throughout May and until June 24 and 27, respectively. Warnings of these floods were issued in each case as the necessity therefor arose.—*I. M. Cline.*

Estimated loss by flood.

River and district.	Farm buildings, machinery, live stock, etc.	Suspension of business.	Value of warnings.	Tangible property, roads, bridges, etc.	Crops.	
					Matured.	Prospective.
Mississippi:						
New Orleans	$12,500	$50,000	$45,000	$250	$51,500	$460,000
Red:						
New Orleans			25,000			120,000
Total	12,500	50,000	70,000	250	51,500	580,000

TABLE I.—*Flood stages for the month of June, 1920.*

River and station.	Flood stage.	Above flood stages—dates.		Crest.	
		From—	To—	Stage.	Date.
ATLANTIC DRAINAGE.					
Santee:	*Feet.*			*Feet.*	
Rimini, S. C	12	10	10	12.0	10
Saluda:					
Pelzer, S. C	7	6	6	8.0	6

TABLE I.—*Flood stages for the month of June, 1920*—Continued.

River and station.	Flood stage.	Above flood stages—dates.		Crest.	
		From—	To—	Stage.	Date.
EAST GULF DRAINAGE.					
Apalachicola:	*Feet.*			*Feet.*	
River Junction, Fla.	12	9	9	12.0	9
MISSISSIPPI DRAINAGE.					
Kiskiminetas:					
Saltsburg, Pa.	8	17	18	10.5	17
Tuscarawas:					
Coshocton, Ohio.	8	20	20	8.5	20
Mississippi:					
Arkansas City, Ark.	42	(1)	13	54.0	[3] 11
Vicksburg, Miss.	45	(1)	13	50.8	[3] 19-28
Donaldsonville, La.	28	(1)	23	32.6	[4] 18, 19; [4] 23-25
New Orleans, La.	18	(1)	22	20.4	[4] 17, 18
Illinois:					
Henry, Ill.	7	(1)	7	16.2	[3] 24
Havana, Ill.	14	(1)	5	19.7	[3] 26-28
Beardstown, Ill.	12	(1)	16	21.3	[3] 27
Pearl, Ill.	12	(1)	11	19.1	[3] 27
Missouri:					
Running Water, S. Dak.	16	24	24	16.0	24
Grand:					
Brunswick, Mo.	10	(1)	1	13.1	[4] 22
Do.	10	6	6	10.0	6
Do.	10	9	9	10.3	9
Do.	10	27	(2)	11.7	30
Tallahatchie:					
Swan Lake, Miss.	25	(1)	22	29.1	[4] 3-7
Red:					
Alexandria, La.	36	(1)	6	37.1	2, 3
Ouachita:					
Monroe, La.	40	(1)	12	41.0	5
Atchafalaya:					
Simmesport, La.	41.0	(1)	24	46.7	[4] 21, 22; [4] 24-28
Melville, La.	37	(1)	27	42.5	[4] 20-26
White:					
Georgetown, Ark.	22	(1)	9	23.0	[4] 28
Cache:					
Patterson, Ark.	9	(1)	9	10.2	[4] 18-20
WEST GULF DRAINAGE.					
Trinity:					
Dallas, Tex.	25	20	26	32.1	21
Trinidad, Tex.	28	28	(2)	29.4	29
Liberty, Tex.	25	(1)	16	27.2	9-12
Rio Grande:					
San Marcial, N. Mex.	14	(1)	4	16.1	[4] 27-4
Colorado:					
Topock, Ariz.	14	(1)	20	24.4	2
Yuma, Ariz.	25	(1)	22	30.5	8
Grand:					
State Bridge, Colo.	9	(1)	21	11.4	1, 10, 11
Do.	9	23	26	9.4	25
Do.	9	28	(2)	9.2	29
WEST GULF DRAINAGE—continued.					
Grand—Continued.	*Feet.*			*Feet.*	
Grand Junction, Colo.	11	(1)	3	11.4	2
Fruita, Colo.	12	(1)	16	15.0	[4] 23
Eagle:					
Eagle, Colo.	5	(1)	1	5.0	[4] 31, 1
Do.	5	9	9	5.0	9
Gunnison:					
Sapinero, Colo.	16	(1)	30	20.2	1
Do.	16	20	20	16.0	20
Do.	16	22	24	16.3	22
Do.	16	26	(2)	16.5	28-29
Delta, Colo.	9	(1)	11	10.3	[4] 22
North Fork Gunnison:					
Paonia, Colo.	8	(1)	16	9.9	[4] 22
Green:					
Green River, Colo.	9	(1)	3	9.8	1
Do.	9	8	28	10.9	12
Elgin, Utah.	13	(1)	5	14.0	3
San Juan:					
Farmington, N. Mex.	8	28	28	8.0	28
PACIFIC DRAINAGE.					
Columbia:					
Marcus, Wash.	24	18	(2)	26.6	26, 27
Vancouver, Wash.	15	20	28	15.2	26, 27

[1] Continued from May. [2] Continued into July. [3] April. [4] May.

MEAN LAKE LEVELS DURING JUNE, 1920.

By UNITED STATES LAKE SURVEY.

[Dated: Detroit, Mich., July 7, 1920.]

The following data are reported in the "Notice to Mariners" of the above date:

Data.	Lakes.*			
	Superior.	Michigan and Huron.	Erie.	Ontario.
Mean level during June, 1920:	*Feet.*	*Feet.*	*Feet.*	*Feet.*
Above mean sea level at New York	602.75	580.86	572.49	245.56
Above or below—				
Mean stage of May, 1920	+0.35	+0.13	+0.18	−0.04
Mean stage of June, 1919	+0.31	−0.62	−1.28	−2.39
Average stage for June, last 10 years	+0.49	0.00	−0.42	−1.37
Highest recorded June stage	−0.68	−2.74	−2.03	−3.07
Lowest recorded June stage	+1.51	+0.96	+0.92	+0.67
Average relation of the June level to:				
May level	....	+0.30	+0.20	+0.20
July level	....	−0.10	+0.10	+0.10

*Lake St. Clair's level: In June, 575.42 feet.

EFFECT OF WEATHER ON CROPS AND FARMING OPERATIONS, JUNE, 1920.

By J. WARREN SMITH, Meteorologist in Charge.

The weather during June was, on the whole, very favorable for farming operations and the development of vegetation in nearly all sections of the country. Rainfall occurred mostly in the form of local showers, was fairly well distributed through the month, and the monthly totals were moderate in most districts east of the Rocky Mountains, except that they were large in the central Gulf area, some north-central border States and locally in the Northeast; the June temperatures averaged generally near the normal in all sections of the country. These conditions permitted rapid progress in seasonal farm operations; good cultivation of row crops was accomplished while generally favorable weather the latter part of the month permitted rapid progress in harvesting winter wheat in the central and southern portions of the belt.

The first week of the month was generally too cool for corn in most central and northern districts and there was some further delay in planting in some interior localities on account of wet soil, but thereafter the weather was more favorable, especially the higher temperatures and more sunshine, and corn made mostly satisfactory advance. Much better weather prevailed during June than during the preceding month throughout the cotton belt, with resulting steady, and in some cases rather pronounced, improvement in the cotton crop. The improvement continued throughout the month and was such as to bring the condition of the crop up to nearly an average for the season in some States, particularly in South Carolina, Louisiana, and Oklahoma, but in the southeastern portion of the belt the crop was still in rather poor condition, especially in Alabama, Mississippi, and Georgia.

Both winter and spring wheat made satisfactory development during the month, spring wheat especially showing steady, and in some cases substantial, improvement, and at the close of the month this crop was considerably better than the average, although too much moisture somewhat unfavorably affected it in some of the eastern districts of the belt, particularly in Minnesota. Oats, barley, and other small grains made satisfactory advancement quite generally.

Potatoes and truck crops did well as a rule, although there was some frost damage in the far Northwest during the last decade of the month, and there was too much moisture in some north-central districts, while it was rather cool for best results in some central sections during part of the month. Meadows, pastures, and stock continued in satisfactory condition throughout the month and at its close stock were reported to be in good to excellent condition in all the range States; the cutting of alfalfa and other hay and forage crops progressed well.

CLIMATOLOGICAL TABLES.*

CONDENSED CLIMATOLOGICAL SUMMARY.

In the following table are given for the various sections of the climatological service of the Weather Bureau the monthly average temperature and total rainfall; the stations reporting the highest and lowest temperatures, with dates of occurrence; the stations reporting the greatest and least total precipitation; and other data as indicated by the several headings.

The mean temperature for each section, the highest and lowest temperatures, the average precipitation, and the greatest and least monthly amounts are found by using all trustworthy records available.

The mean departures from normal temperatures and precipitation are based only on records from stations that have 10 or more years of observations. Of course the number of such records is smaller than the total number of stations.

Condensed climatological summary of temperature and precipitation by sections, June, 1920.

Section.	Temperature.								Precipitation.					
	Section average.	Departure from the normal.	Monthly extremes.						Section average.	Departure from the normal.	Greatest monthly.		Least monthly.	
			Station.	Highest.	Date.	Station.	Lowest.	Date.			Station.	Amount.	Station.	Amount.
	°F.	°F.		°F.			°F.		In.	In.		In.		In.
Alabama	77.0	−1.1	4 stations	101	14†	Maple Grove	50	6	4.50	+0.19	St. Bernard	8.96	Healing Springs	0.55
Arizona	74.1	−0.9	2 stations	115	21	2 stations	31	1†	0.60	+0.30	Kingman	3.00	9 stations	0.00
Arkansas	74.8	−1.7	Marked Tree	101	26	Dutton	42	26	3.41	−0.93	Conway	8.26	Dodd City	0.63
California	67.3	−1.7	Blythe	119	21	Portola	20	8	0.42	+0.11	Crescent City	7.49	58 stations	0.00
Colorado	59.9	−0.6	Sedgwick	100	8	Crested Butte	15	20	1.51	+0.19	Peetz	5.31	Salida	0.00
Florida	78.8	−1.0	Live Oak	102	13	Quincy	55	9	5.98	−0.35	Brooksville	13.28	Sand Key	0.84
Georgia	77.7	−0.1	Statesboro	105	16	Ramhurst	47	6	3.37	−1.10	Bainbridge	7.58	Athens	0.69
Hawaii (May)	72.9	+1.3	Mahukona	94	15	3 stations	50	10†	2.48	−3.27	Holualoa	17.38	5 stations	0.00
Idaho	59.0	−1.0	Glenns Ferry	102	28	Stanley	15	2	0.99	−0.41	Elk City	3.05	Buhl	T.
Illinois	72.1	+0.8	15 stations	97	13†	Joliet	37	6	2.15	−1.65	La Harpe	8.46	Sparta	0.25
Indiana	70.0	−1.6	2 stations	100	11†	Hobart	36	6	3.03	−0.72	Albion	6.53	Farmersburg	0.65
Iowa	70.7	+1.6	2 stations	99	13	8 stations	40	17	3.55	−0.83	Britt	8.48	Des Moines	1.25
Kansas	72.8	0.0	4 stations	102	15†	3 stations	39	4†	2.96	−1.15	Osage City	9.05	Cawker City	0.44
Kentucky	71.9	−1.8	Greenville	100	27	Anchorage	44	6	3.12	−1.06	Middlesboro	6.32	Marion	0.70
Louisiana	78.7	−1.5	Cheneyville	100	15	Plain Dealing	51	19	5.21	+0.42	Lakeside	9.80	Ruston	1.63
Maryland-Delaware	70.2	−0.5	Frederick, Md	98	11	Oakland, Md	34	7	5.37	+1.34	Friendsville, Md	8.27	Fairview, Md	2.86
Michigan	64.8	+1.4	Eloise	102	10	Humboldt	28	6	3.85	+0.90	Iron Mountain	6.80	Battle Creek	1.35
Minnesota	64.9	+1.0	4 stations	97	13†	Grand Rapids	28	3	5.95	+1.91	St. Cloud	10.56	Hallock	0.74
Mississippi	77.3	−1.4	5 stations	101	14†	2 stations	53	7	4.53	+0.10	Pearlington	9.14	Laurel	0.89
Missouri	72.7	−0.5	Caruthersville	104	14†	Edgerton	41	5	2.35	−2.16	Kansas City	6.63	Patton (near)	0.60
Montana	57.7	−1.9	Sidney	97	8	2 stations	20	1†	2.15	−0.58	Malta	7.20	Browning	0.24
Nebraska	68.9	−0.2	2 stations	100	14†	Harrison	29	2	2.95	−0.87	Walthill	7.85	Alliance	0.81
Nevada	63.9	−1.0	Logandale	109	21†	San Jacinto	19	2	0.58	−0.03	Reno	1.94	Lovelock	T.
New England	63.0	−1.3	Vernon, Vt	100	2	Woodland, Me	23	6	4.51	+1.35	Canton, Conn	9.13	Houlton, Me	0.60
New Jersey	68.4	−0.8	Imlaystown	98	29	Charlotteburg	38	8	6.18	+2.38	Pleasantville	11.26	Phillipsburg	3.12
New Mexico	66.7	−1.7	Elephant Butte Dam	105	27	Senorito (near)	25	20	2.31	+0.81	Carson Seep R. S.	7.84	Tijeras Canyon	0.16
New York	64.2	−0.6	2 stations	95	1†	Indian Lake	32	4†	3.65	+0.06	Roslyn	7.73	Appleton	0.96
North Carolina	72.9	−0.4	3 stations	102	17†	Jefferson	40	7	4.87	−0.32	Highlands	9.97	Southport	0.84
North Dakota	62.2	−0.6	Mott	98	8	Mott	28	3	3.62	+0.12	Epping	7.42	Pembina	0.50
Ohio	68.9	−0.1	5 stations	98	10†	2 stations	38	6	4.53	+1.01	2 stations	8.65	Versailles	2.16
Oklahoma	75.7	−0.8	Mutual	107	30	2 stations	47	20	2.70	−1.17	Newkirk	5.58	Apache	0.66
Oregon	59.4	−0.7	2 stations	101	21†	3 stations	15	1	1.69	+0.23	Brookings	7.62	Vale	0.07
Pennsylvania	67.0	−0.4	Ephrata	99	29	West Bingham	32	4†	4.97	+0.83	West Newton	8.37	York	2.25
Porto Rico	78.0	−0.4	Manati	99	4†	Aibonito	56	14	3.33	−3.37	Las Marias	9.95	Coamo	0.30
South Carolina	77.4	−0.1	St. Matthews	105	16	4 stations	52	8	3.41	−1.54	Georgetown	6.57	Walterboro	0.76
South Dakota	64.9	−0.3	Gannvalley	103	12	Ellingson	27	4	4.79	+1.65	De Smet	11.41	Hardingrove	0.83
Tennessee	73.1	−1.6	Covington	98	15	Mountain City	41	7	4.62	+0.41	Union City	7.45	Bolivar	1.59
Texas	78.1	−2.1	Coleman	106	17	3 stations	48	3†	3.58	+0.39	Hitchcock	11.35	Buena Vista	0.81
Utah	63.1	−0.5	St. George	105	21	Blacks Fork	16	1	0.47	−0.21	New Harmony	1.54	10 stations	T.
Virginia	70.3	−1.8	2 stations	99	11†	Burke's Garden	35	7	5.37	+1.04	Speers Ferry	8.05	Narrows	2.25
Washington	59.5	−1.4	Hanford	102	30	Colfax	26	26	1.68	−0.02	Quiniault	12.50	Lakeside	T.
West Virginia	67.9	−0.9	Charleston	98	29	2 stations	36	7	5.01	+0.52	Wellsburg	9.70	Spencer	2.53
Wisconsin	65.9	+1.5	Ripon	100	10	3 stations	30	3†	6.39	+2.50	Mondovi	10.44	Plum Island	2.15
Wyoming	57.0	−0.9	Pine Ridge	103	8	Gallatin	10	1	1.34	−0.43	Sundance	5.12	2 stations	0.00

* For description of tables and charts see this REVIEW, January, 1920, p. 54.

† Other dates also.

TABLE I.—*Climatological data for Weather Bureau stations, June, 1920.*

Districts and stations.	Elevation of instruments: Barometer above sea level.	Elevation of instruments: Thermometer above ground.	Elevation of instruments: Anemometer above ground.	Pressure: Station, reduced to mean of 24 hours.	Pressure: Sea level, reduced to mean of 24 hours.	Pressure: Departure from normal.	Temperature of the air: Mean max. + mean min. ÷ 2.	Temperature: Departure from normal.	Temperature: Maximum.	Temperature: Date.	Temperature: Mean maximum.	Temperature: Minimum.	Temperature: Date.	Temperature: Mean minimum.	Temperature: Greatest daily range.	Mean wet thermometer.	Mean temperature of the dew-point.	Mean relative humidity.	Precipitation: Total.	Precipitation: Departure from normal.	Precipitation: Days with 0.01 inch or more.	Wind: Total movement.	Wind: Prevailing direction.	Wind: Maximum velocity: Miles per hour.	Wind: Maximum velocity: Direction.	Wind: Maximum velocity: Date.	Clear days.	Partly cloudy days.	Cloudy days.	Average cloudiness, tenths.	Total snowfall.	Snow, sleet, and ice on ground at end of month.
	Ft.	Ft.	Ft.	In.	In.	In.	°F.	°F.	°F.		°F.	°F.		°F.	°F.	°F.	°F.	%	In.	In.		Miles.								0–10	In.	In.
New England.							**62.5**	**−1.0**										**78**	**4.78**	**+1.7**										**6.3**		
Eastport	76	67	85	29.84	29.92	−.01	54.8	+0.4	78	14	63	42	7	47	32	50	47	79	1.95	−1.3	10	7,382	s.	50	ne.	6	6	12	12	6.0	0.0	0.0
Greenville, Me.	1,070	6	....	28.79	29.94	......	59.8	......	85	1	72	40	9	48	38	....	....	....	3.12	......	13	......	......	....	......	....	12	8	10	....	0.0	0.0
Portland, Me.	103	82	117	29.83	29.95	00	62.0	−0.6	92	1	70	46	10	54	35	55	51	72	2.73	−0.6	11	5,808	s.	30	ne	6	10	7	13	5.8	0.0	0.0
Concord	288	70	79	29.64	29.95	−.01	64.8	+0.4	92	2	75	43	20	55	35				3.68	+0.3	13	3,000	nw.	26	sw.	29	8	8	14	6.4	0.0	0.0
Burlington	404	11	48	29.51	29.94	−.02	63.4	−0.4	85	2	73	47	8	54	34				4.01	+0.8	13	5,383	s.	27	s.	28	4	13	13	6.6	0.0	0.0
Northfield	876	12	60	29.02	29.96	00	60.4	−2.3	88	2	72	39	20	48	41	56	53	77	3.60	+0.4	16	3,685	s.	23	n.	12	2	13	15	7.1	0.0	0.0
Boston	125	115	188	29.81	29.94	−.02	65.8	0.0	90	2	74	47	18	58	32	60	56	75	5.78	+2.8	9	6,729	sw.	39	e.	18	9	8	13	6.5	0.0	0.0
Nantucket	12	14	90	29.94	29.95	−.03	59.1	−2.2	77	15	65	48	5	53	23	56	55	92	3.58	+1.2	13	10,992	sw.	45	ne.	18	5	11	14	6.4	0.0	0.0
Block Island	26	11	46	29.93	29.96	−.01	60.8	−0.8	78	15	66	48	19	55	20	58	58	94	5.75	+2.9	11	11,075	sw.	48	e.	17	7	10	13	6.5	0.0	0.0
Providence	160	215	251	29.78	29.95	−.02	64.6	−2.7	91	11	74	46	18	56	35	58	54	71	6.80	+3.7	13	7,697	sw.	41	sw.	29	7	11	12	6.1	0.0	0.0
Hartford	159	122	140	29.78	29.96	−.01	65.7	−1.4	89	11	75	47	19	56	33	59	54	72	8.00	+4.9	12	4,760	s.	27	nw.	30	7	8	15	6.5	0.0	0.0
New Haven	106	74	153	29.85	29.96	−.01	66.0	−0.9	91	11	75	48	19	57	33	59	56	73	6.62	+3.4	12	5,871	sw.	47	ne.	11	10	10	10	5.6	0.0	0.0
Middle Atlantic States.							**69.5**	**−0.7**										**72**	**5.66**	**+2.0**										**5.5**		
Albany	97	102	115	29.84	29.94	−.03	66.6	−1.3	90	15	76	48	19	57	28	60	55	68	5.21	+1.4	12	4,349	s.	26	sw.	29	12	8	10	5.2	0.0	0.0
Binghamton	871	10	84	29.05	29.96	−.01	65.3	−0.9	91	29	76	45	4	54	38				3.86	+0.3	14	3,248	w.	42	w.	29	6	10	14	6.5	0.0	0.0
New York	314	414	454	29.62	29.95	−.03	67.6	−0.9	90	11	76	50	5	59	28	60	56	71	6.19	+2.9	13	10,237	sw.	50	sw.	15	6	16	8	5.9	0.0	0.0
Harrisburg	374	94	104	29.59	29.98	−.01	69.8	−0.5	93	29	80	50	5	60	27	61	56	67	3.68	+0.1	12	3,700	w.	42	w.	16	4	15	11	6.1	0.0	0.0
Philadelphia	117	123	190	29.85	29.97	−.01	71.2	0.0	95	29	80	53	5	62	27	63	58	68	6.76	+3.5	13	5,856	sw.	32	n.	30	8	12	10	5.6	0.0	0.0
Reading	325	81	98	29.63	29.97	......	70.0	......	95	11	80	51	5	60	29	62	57	66	3.35	−0.3	12	3,587	sw.	28	nw.	16	11	2	17	6.0	0.0	0.0
Scranton	805	111	119	29.13	29.98	00	66.9	−0.3	91	29	78	49	8	56	34	59	55	68	5.00	+1.4	12	4,229	sw.	31	ne.	29	3	12	15	6.9	0.0	0.0
Atlantic City	52	37	48	29.91	29.97	−.01	67.5	+0.7	87	28	74	53	7	61	24	62	60	79	8.45	+5.4	12	5,302	sw.	33	nw.	17	11	13	6	4.6	0.0	0.0
Cape May	18	13	49	29.99	30.01	+.03	69.2	+1.5	90	30	76	56	4	63	24	63	61	82	5.36	+2.3	13	5,276	s.	45	nw.	16	11	11	8	4.5	0.0	0.0
Sandy Hook	22	10	57	29.94	29.96	......	67.4	......	89	11	75	51	5	60	25	62	60	81	6.69	......	13	8,824	sw.	43	s.	29	6	15	9	6.2	0.0	0.0
Trenton	190	159	183	29.76	29.96	......	69.0	......	93	29	79	49	5	59	31	62	58	72	6.63	+3.1	12	7,053	sw.	43	nw.	17	6	14	10	6.0	0.0	0.0
Baltimore	123	100	113	29.85	29.98	−.01	72.6	−0.4	97	11	82	54	4	63	30	64	60	67	8.25	+4.4	13	4,344	sw.	40	nw.	16	9	11	10	5.4	0.0	0.0
Washington	112	62	85	29.86	29.98	−.02	71.6	−1.1	95	11	82	54	10	61	30	64	60	72	4.80	+0.6	12	3,929	nw.	36	nw.	17	7	10	13	5.8	0.0	0.0
Lynchburg	681	153	188	29.27	30.00	−.01	71.9	−1.6	94	11	83	48	7	60	34	64	60	70	5.12	+1.2	11	4,512	w.	36	n.	17	10	4	6	5.2	0.0	0.0
Norfolk	91	170	205	29.90	30.00	00	74.3	−0.1	95	17	83	57	7	65	25	66	62	70	5.05	+0.7	11	8,311	s.	42	nw.	25	14	10	6	4.5	0.0	0.0
Richmond	144	11	52	29.85	30.00	−.01	72.4	−2.7	95	12	83	53	7	62	29	66	63	76	6.34	+2.8	12	4,676	sw.	29	ne.	13	9	6	15	5.9	0.0	0.0
Wytheville	2,304	49	56	27.70	30.02	+.01	66.6	−2.3	86	11	77	45	7	56	31	61	58	76	6.54	+2.4	12	3,811	w.	34	w.	17	19	6	5	3.5	0.0	0.0
South Atlantic States.							**76.1**	**−0.1**										**72**	**4.10**	**−0.8**										**4.4**		
Asheville	2,255	70	84	27.75	30.04	+.03	68.6	−0.1	88	17	79	50	1	58	27	61	58	74	2.42	−1.9	10	4,425	nw.	26	e.	19	12	11	7	4.4	0.0	0.0
Charlotte	779	55	62	29.18	30.00	−.01	75.6	+0.1	96	16	86	56	7	66	29	66	61	65	3.56	−0.9	7	3,193	sw.	18	w.	17	14	8	8	4.3	0.0	0.0
Hatteras	11	12	50	30.00	30.01	00	71.7	−2.7	89	30	78	59	8	65	21	69	67	86	3.97	−0.4	10	8,576	sw.	30	ne.	6	13	9	8	4.8	0.0	0.0
Manteo	12	5	42	......	......	......	......	......	....	....	....	....	....	....	....	....	....	....	......	......	....	......	......	....	......	....	....	....	....	....	....	....
Raleigh	376	103	110	29.61	30.00	−.01	75.2	+0.1	96	16	85	57	8	65	28	66	62	69	4.83	+0.1	12	5,343	sw.	35	nw.	15	12	9	9	5.3	0.0	0.0
Wilmington	78	81	91	29.95	30.03	+.02	76.2	+0.7	98	12	85	57	8	68	28	68	65	74	3.96	−1.7	7	5,350	w.	28	sw.	21	15	10	5	4.3	0.0	0.0
Charleston	48	11	92	29.97	30.02	+.01	78.4	−0.1	97	17	85	63	9	71	24	71	68	74	2.45	−2.9	5	7,670	sw.	35	s.	23	10	11	9	5.1	0.0	0.0
Columbia, S. C.	351	41	57	29.65	30.02	+.01	78.6	+0.4	100	16	89	58	8	68	28	68	62	64	2.16	−2.0	7	4,523	s.	24	sw.	20	16	9	5	3.8	0.0	0.0
Greenville, S. C.	1,039	113	122	28.93	30.00	......	75.0	......	94	13	84	57	8	66	31	65	61	66	6.11	......	7	5,397	w.	37	n.	5	13	10	7	4.6	0.0	0.0
Augusta	180	62	77	29.81	30.00	−.01	79.5	+1.4	100	16	90	60	8	69	30	69	64	63	3.22	−1.3	5	3,728	nw.	20	w.	17	15	8	7	3.8	0.0	0.0
Savannah	65	150	194	29.96	30.03	+.02	78.2	0.0	100	16	87	63	9	69	30	70	68	76	6.16	+0.1	10	7,674	sw.	33	e.	7	14	8	8	5.0	0.0	0.0
Jacksonville	43	209	245	29.98	30.03	+.02	78.6	−0.4	95	13	86	66	10	72	22	72	70	80	8.27	+2.7	10	8,397	s.	38	s.	5	19	6	5	3.3	0.0	0.0
Florida Peninsula.							**80.1**	**−0.8**										**74**	**3.93**	**−2.9**										**5.2**		
Key West	22	10	64	29.98	30.00	+.01	81.4	−0.8	89	21	86	69	29	76	15	74	71	73	3.41	−0.8	8	6,284	e.	27	nw.	7	10	14	6	4.7	0.0	0.0
Miami	25	71	79	30.00	30.02	......	79.2	−1.2	86	17	84	65	12	74	18	74	71	75	3.90	−4.0	12	5,289	e.	26	e.	27	6	11	13	6.3	0.0	0.0
Sand Key	23	39	72	29.95	29.98	......	80.0	......	87	15	82	69	28	78	12	74	71	74	0.84	......	6	7,919	se.	37	se.	28	14	10	6	4.4	0.0	0.0
Tampa	35	79	92	29.99	30.02	+.01	79.6	−0.4	92	19	87	67	10	72	21	72	70	76	4.49	−3.8	15	4,499	ne.	26	sw.	6	9	12	9	5.5	0.0	0.0
East Gulf States.							**78.1**	**−0.2**										**70**	**4.45**	**−0.1**										**4.3**		
Atlanta	1,174	190	216	28.82	30.03	+.02	76.4	+0.8	94	11	85	58	6	67	23	66	61	64	3.47	−0.4	6	6,370	w.	34	w.	20	16	9	5	4.1	0.0	0.0
Leesburg	279	10	55	29.73	30.03	......	78.0	......	98	16	89	59	29	67	33	69	65	69	2.70	......	8	4,454	e.	30	sw.	20	8	11	11	5.9	0.0	0.0
Macon	370	78	87	29.62	30.01	.00	78.4	+1.3	99	16	89	60	8	68	32	68	62	62	2.52	−1.1	7	3,941	sw.	28	s.	17	15	8	7	4.3	0.0	0.0
Thomasville	273	49	58	29.72	30.01	+.01	79.0	−0.5	99	15	89	59	9	69	28	70	67	73	3.22	−1.5	12	3,184	ne.	20	sw.	5	10	8	12	5.6	0.0	0.0
Pensacola	56	149	185	29.95	30.01	+.02	78.4	−1.6	94	13	84	66	12	73	28	72	69	74	4.39	−0.5	9	8,124	sw.	50	sw.	19	13	10	7	4.8	0.0	0.0
Anniston	741	9	57	29.26	30.04	+.04	74.8	−0.2	95	15	87	56	6	63	34	....	....	....	5.52	+1.6	10	2,791	n.	20	sw.	19	19	8	3	2.9	0.0	0.0
Birmingham	700	11	48	29.29	30.04	+.05	76.7	−1.5	94	15	87	57	6	66	27	67	63	67	3.63	−0.2	6	3,625	n.	18	s.	19	18	8	4	3.4	0.0	0.0
Mobile	57	125	161	29.95	30.01	+.02	79.8	+0.7	98	14	88	65	7	72	24	72	69	74	6.64	+0.7	10	5,678	sw.	43	w.	16	9	18	3	4.7	0.0	0.0
Montgomery	223	100	112	29.77	30.02	+.02	79.2	+0.1	98	16	88	62	6	70	25	69	64	64	4.11	−0.1	7	4,221	sw.	28	nw.	19	21	5	4	3.1	0.0	0.0
Corinth	469	6	....	......	......	......	......	......	....	....	....	....	....	....	....	....	....	....	......	......	....	......	......	....	......	....	....	....	....	....	....	....
Meridian	375	85	93	29.62	30.00	+.02	77.1	−0.2	96	15	87	58	7	67	28	69	66	72	3.79	−0.8	7	2,974	sw.	21	nw.	23	19	6	5	3.8	0.0	0.0
Vicksburg	247	65	74	29.74	30.02	+.05	78.2	−0.3	93	14	87	64	20	70	22	70	67	73	3.22	−1.3	8	3,873	se.	16	s.	2	15	9	6	4.5	0.0	0.0
New Orleans	53	76	84	29.95	30.00	+.02	80.8	+1.2	96	14	88	68	1	74	20	73	70	74	8.45	+2.3	13	3,972	se.	20	e.	28	11	13	6	4.8	0.0	0.0
West Gulf States.							**77.6**	**−1.4**										**73**	**3.44**	**−0.3**										**4.5**		
Shreveport	249	77	93	29.74	30.00	+.04	78.5	−1.1	95	15	88	62	21	69	27	69	66	69	5.23	+1.6	6	4,339	se.	19	nw.	22	21	5	4	3.3	0.0	0.0
Bentonville	1,303	11	44	28.65	29.99	+.05	71.6	−2.5	92	16	82	51	6	61	30	....	....	....	2.02	−2.5	6	3,157	s.	26	w.	16	16	6	8	4.4	0.0	0.0
Fort Smith	457	79	94	29.51	29.98	+.04	76.1	−0.7	95	30	86	57	23	66	28	67	63	67	1.71	−2.3	8	4,765	e.	25	s.	15	13	7	10	4.8	0.0	0.0
Little Rock	357	139	147	29.64	30.01	+.05	75.4	−1.8	93	30	84	56	19	66	24	68	64	71	4.27	+0.2	8	5,013	s.	46	nw.	17	18	6	6	3.8	0.0	0.0
Brownsville	57	4	26	......	......	......	81.5	......	98	20	91	68	10	72	26	....	....	....	6.70	......	11	......	......	....	......	....	....	....	....	....	....	....
Corpus Christi	20	69	77	29.94	29.96	+.05	80.4	−0.2	92	22	86	68	19	75	18	75	72	78	2.48	−0.3	11	8,511	se.	36	n.	19	16	7	7	4.1	0.0	0.0
Dallas	512	109	117	29.44	29.98	......	78.4	......	94	30	87	62	19	69	24	....	....	....	4.29	......	7	5,689	s.	31	ne.	19	14	12	4	4.1	0.0	0.0
Fort Worth	670	106	114	29.25	29.95	+.03	78.3	−1.8	94	30	88	62	21	68	29	69	65	69	2.33	−0.6	7	6,771	s.	36	nw.	17	13	13	4	4.4	0.0	0.0
Galveston	54	106	114	29.94	30.00	+.05	79.6	−1.3	89	14	84	68	6	75	14	73	71	75	6.68	+1.9	13	6,628	se.	31	se.	2	11	15	4	4.3	0.0	0.0
Groesbeck	461	11	56	29.48	29.95	......	77.8	......	93	16	88	61	21	67	28	70	68	77	2.45	......	11	6,012	s.	54	ne.	22	15	12	3	4.1	0.0	0.0
Houston	138	111	121	29.83	29.98	......	79.4	−1.6	93	14	88	65	20	71	23	....	....	....	3.81	......	10	4,835	se.	29	se.	11	10	17	3	4.3	0.0	0.0
Palestine	510	64	72	29.46	29.98	+.04	77.8	−0.6	93	16	88	62	21	68	25	69	66	73	2.88	−1.1	7	4,320	s.	34	ne.	22	10	14	6	5.1	0.0	0.0
Port Arthur	34	58	66	29.94	29.98	......	78.7	......	90	14	85	67	18	72	18	73	70	78	10.12	......	11	5,578	se.	31	nw.	18	11	13	6	5.2	0.0	0.0
San Antonio	701	119	132	29.25	29.96	+.06	78.4	−2.0	92	18	88	63	23	69	26	71	68	76	2.83	−0.3	13	4,950	se.	36	ne.	22	8	15	7	5.3	0.0	0.0
Taylor	582	55	63	29.40	30.01	+.09	78.1	−1.9	94	16	88	63	20	68	28	....	....	....	3.97	+0.4	8	5,083	se.	42	w.	19	5	17	8	5.8	0.0	0.0

TABLE I.—*Climatological data for Weather Bureau Stations, June, 1920*—Continued.

Districts and stations.	Elevation of instruments: Barometer above sea level.	Elevation: Thermometer above ground.	Elevation: Anemometer above ground.	Pressure: Station, reduced to mean of 24 hours.	Pressure: Sea level, reduced to mean of 24 hours.	Pressure: Departure from normal.	Temperature: Mean max. + mean min. ÷ 2.	Temperature: Departure from normal.	Temperature: Maximum.	Temperature: Date.	Temperature: Mean maximum.	Temperature: Minimum.	Temperature: Date.	Temperature: Mean minimum.	Temperature: Greatest daily range.	Mean wet thermometer.	Mean temperature of the dew-point.	Mean relative humidity.	Precipitation: Total.	Precipitation: Departure from normal.	Precipitation: Days with 0.01 inch or more.	Wind: Total movement.	Wind: Prevailing direction.	Wind: Maximum velocity: Miles per hour.	Wind: Maximum velocity: Direction.	Wind: Maximum velocity: Date.	Clear days.	Partly cloudy days.	Cloudy days.	Average cloudiness, tenths.	Total snowfall.	Snow, sleet, and ice on ground at end of month.
	Ft.	Ft.	Ft.	In.	In.	In.	° F.	° F.	° F.		° F.	° F.		° F.	° F.	° F.	° F.	%	In.	In.		Miles.								0-10	In.	In.
Ohio Valley and Tennessee.							71.4	−1.5										68	4.03	−0.2										5.2		
Chattanooga	762	189	213	29.24	30.04	+.04	74.0	−1.4	93	14	84	58	6	64	27	66	62	71	5.97	+1.7	10	4,357	sw.	34	sw.	17	13	9	8	5.0	0.0	0.0
Knoxville	996	102	111	28.98	30.02	+.02	73.4	0.0	92	13	83	54	6	64	26	65	61	70	7.18	+3.0	11	3,530	ne.	27	sw.	17	9	10	11	5.9	0.0	0.0
Memphis	399	76	97	29.63	30.05	+.08	76.5	−1.2	94	14	84	61	7	69	23	67	63	66	1.83	−2.5	8	4,911	sw.	28	nw.	17	16	6	8	4.2	0.0	0.0
Nashville	546	168	191	29.46	30.03	+.04	73.8	−2.5	93	15	83	56	21	64	26	65	61	68	3.81	−0.6	8	5,052	w.	53	nw.	21	14	13	3	4.3	0.0	0.0
Lexington	989	193	230	28.97	30.02	+.02	71.3	−1.9	90	27	80	52	6	63	23				2.39	−1.6	11	8,458	sw.	38	sw.	2	15	7	8	4.5	0.0	0.0
Louisville	525	219	255	29.45	30.02	+.04	72.8	−2.2	93	14	82	52	18	64	28	64	59	65	1.72	−2.5	8	7,526	sw.	40	s.	16	18	5	7	3.9	0.0	0.0
Evansville	431	139	175	29.56	30.02	+.05	74.2	−1.1	96	14	84	50	18	64	28	65	60	64	3.77	−0.4	8	6,768	sw.	36	sw.	16	12	15	3	4.3	0.0	0.0
Indianapolis	822	194	230	29.14	30.01	+.04	71.1	−1.3	92	13	80	50	18	62	25	62	57	65	3.78	−0.5	9	7,479	sw.	48	nw.	13	11	10	9	5.2	0.0	0.0
Royal Center	736	11	55	29.21	30.00	.....	69.2	.....	93	10	80	46	6	58	33	62	58	70	3.08	.....	12	6,014	sw.	45	sw.	16	7	14	9	5.5	0.0	0.0
Terre Haute	575	96	129	29.37	29.98	.....	72.5	.....	94	13	82	48	18	62	28	63	58	63	0.98	.....	5	6,287	sw.	29	sw.	16	9	14	7	5.2	0.0	0.0
Cincinnati	628	11	51	29.34	30.01	+.02	70.4	−1.3	91	15	80	49	6	61	31	64	59	68	2.68	−1.3	10	4,603	sw.	30	n.	13	13	7	10	4.9	0.0	0.0
Columbus	824	179	222	29.15	30.00	+.01	69.2	−1.4	91	10	78	47	6	60	26	62	58	69	3.79	+0.3	13	6,808	e.	52	nw.	16	8	12	10	5.6	0.0	0.0
Dayton	899	181	216	29.03	29.97	.....	70.3	−1.9	91	15	80	49	6	61	27	62	57	66	3.75	−0.2	13	6,492	sw.	40	nw.	2	13	9	8	4.6	0.0	0.0
Elkins	1,947	59	67	28.01	30.02	+.02	64.2	−2.4	84	16	75	41	7	54	36	59	56	79	3.83	−1.2	13	3,178	w.	25	sw.	17	3	12	15	6.9	0.0	0.0
Parkersburg	638	77	84	29.38	30.03	+.03	70.2	−1.3	92	16	80	48	7	60	29	62	59	72	5.20	+0.6	13	3,318	sw.	32	nw.	17	10	7	13	6.0	0.0	0.0
Pittsburgh	842	353	410	29.11	30.00	+.01	68.5	−1.7	89	10	77	50	7	60	26	61	57	70	6.74	+2.8	14	7,234	sw.	50	n.	13	3	12	15	6.8	0.0	0.0
Lower Lake Region.							66.5	−0.6										69	3.41	−0.1										5.5		
Buffalo	767	247	280	29.16	29.98	+.01	64.0	−1.1	82	27	70	49	6	58	25	58	54	74	3.11	0.0	13	9,270	sw.	56	w.	29	6	12	12	6.2	0.0	0.0
Canton	448	10	61	29.46	29.93	.....	63.6	−2.2	87	1	74	42	4	53	33				2.69	−0.7	13	6,064	w.	33	e.	5	10	10	10	5.1	0.0	0.0
Oswego	335	76	91	29.60	29.96	−.01	61.0	−2.8	87	28	70	43	4	52	25	56	53	74	1.52	−1.9	13	5,159	w.	22	se.	5	11	3	16	5.7	0.0	0.0
Rochester	523	86	102	29.42	29.98	+.01	65.7	−0.4	88	28	75	45	19	56	29	58	52	64	1.15	−2.0	13	5,287	sw.	34	w.	29	9	6	15	6.3	0.0	0.0
Syracuse	597	97	113	29.34	29.98	+.01	65.3	−1.6	89	29	74	46	4	57	27				1.54	−2.4	11	6,368	nw.	38	sw.	29	8	13	9	5.7	0.0	0.0
Erie	714	130	166	29.22	29.98	.00	66.3	−0.7	87	10	74	49	6	59	24	60	56	70	3.94	+0.2	13	8,047	w.	41	w.	21	11	13	9	4.9	0.0	0.0
Cleveland	762	190	201	29.18	30.00	+.02	67.4	−0.5	88	28	74	51	5	61	22	61	56	70	5.28	+1.6	12	7,146	sw.	53	w.	16	6	15	9	6.1	0.0	0.0
Sandusky	629	62	103	29.32	30.00	+.02	69.3	−0.5	91	28	77	49	6	62	26				4.63	+0.8	10	7,065	sw.	38	ne.	17	3	21	6	5.5	0.0	0.0
Toledo	628	208	243	29.32	29.99	+.02	70.0	+0.6	92	10	78	51	17	62	25	62	58	68	4.78	+1.4	10	8,192	sw.	38	w.	21	12	15	3	4.6	0.0	0.0
Fort Wayne	856	113	124	29.09	30.00	.....	70.1	+1.6	92	12	80	50	6	60	27	62	56	65	3.35	.....	8	5,753	sw.	34	nw.	14	9	14	7	5.1	0.0	0.0
Detroit	730	218	245	29.21	29.99	+.02	69.0	+1.2	92	11	77	50	17	61	24	60	55	65	5.49	+1.6	10	7,329	w.	35	sw.	28	7	15	8	5.3	0.0	0.0
Upper Lake Region.							63.6	+1.1										71	4.05	+0.7										5.1		
Alpena	609	13	92	29.33	29.99	+.03	61.6	+1.3	88	28	70	42	4	53	29	57	53	75	3.40	−0.2	10	6,431	nw.	36	nw.	10	9	11	10	5.7	0.0	0.0
Escanaba	612	54	60	29.32	29.98	+.04	61.8	+1.2	88	9	69	43	3	54	31	57	54	77	5.33	+1.7	13	6,152	s.	40	n.	16	14	11	5	3.7	0.0	0.0
Grand Haven	632	54	89	29.31	29.98	+.02	63.2	−1.5	84	13	72	46	5	54	31	57	53	70	3.13	+0.6	10	6,945	sw.	34	w.	15	12	11	7	4.7	0.0	0.0
Grand Rapids	707	70	87	29.24	29.96	+.02	69.2	+1.1	92	28	80	49	5	58	29	61	55	65	4.09	+1.6	10	3,473	w.	25	w.	11	11	9	10	5.4	0.0	0.0
Houghton	684	62	99	29.26	29.98	+.04	60.2	+0.8	86	26	71	40	3	50	33	.....	.....	.....	3.49	0.0	13	6,554	e.	44	w.	2	9	12	9	5.4	0.0	0.0
Lansing	878	11	62	29.06	29.99	.....	67.7	+0.3	93	10	79	45	6	56	32	61	56	70	4.17	+0.8	9	3,205	s.	24	nw.	11	11	10	9	5.4	0.0	0.0
Ludington	637	60	66	29.30	30.00	.....	60.0	.....	81	13	69	45	6	51	30	56	52	74	2.91	.....	11	5,999	s.	31	s.	26	11	13	6	4.7	0.0	0.0
Marquette	734	77	111	29.21	30.02	+.08	58.9	+0.4	88	26	69	42	5	49	36	53	49	75	2.80	−0.7	11	5,299	nw.	35	sw.	12	6	12	12	6.2	0.0	0.0
Port Huron	638	70	120	29.29	29.98	+.01	65.4	+1.6	90	12	75	46	6	56	31	59	56	74	2.19	−1.0	8	6,302	ne.	30	n.	17	8	19	3	4.6	0.0	0.0
Saginaw	641	69	77	29.30	29.99	.....	67.5	.....	91	10	78	48	5	57	31	60	56	68	2.88	+0.2	9	5,198	sw.	27	ne.	17	10	11	9	5.4	0.0	0.0
Sault Ste. Marie	614	11	52	29.31	29.99	+.03	60.0	+2.4	84	10	71	37	4	49	37	55	51	75	4.39	+1.6	9	4,366	w.	42	w.	28	11	13	6	4.8	0.0	0.0
Chicago	823	140	310	29.12	30.00	+.04	69.1	+2.8	95	28	77	51	17	62	34	60	55	64	3.94	+0.3	10	8,019	n.	38	w.	1	16	7	7	4.1	0.0	0.0
Green Bay	617	109	144	29.32	29.98	+.03	66.8	+1.7	90	12	76	47	3	57	28	59	55	69	6.00	+2.4	14	7,328	s.	52	ne.	16	9	14	7	5.7	0.0	0.0
Milwaukee	681	125	139	29.25	29.98	+.03	65.4	+1.9	94	12	75	47	5	56	35	58	52	63	5.25	+1.6	8	6,150	ne.	40	ne.	16	7	16	7	5.2	0.0	0.0
Duluth	1,133	11	47	28.77	29.98	+.06	57.9	+0.2	83	9	66	40	3	49	29	54	50	78	5.66	+1.1	12	7,769	ne.	47	ne.	16	10	9	11	5.3	0.0	0.0
North Dakota.							63.6	0.0										70	4.03	+0.4										5.3		
Moorhead	940	8	57	28.96	29.96	+.06	64.8	+0.5	95	13	76	39	5	54	34	59	56	77	5.89	+1.8	14	4,515	s.	46	nw.	8	13	11	6	4.1	0.0	0.0
Bismarck	1,674	8	57	28.21	29.97	+.10	64.4	+0.2	89	13	76	38	2	53	35	56	51	65	2.05	−1.5	12	6,703	nw.	34	sw.	25	7	16	7	5.4	0.0	0.0
Devils Lake	1,482	11	44	28.38	29.93	+.05	62.4	−0.2	86	13	74	37	3	51	36	56	51	69	4.69	+1.2	10	5,969	se.	50	w.	14	12	7	11	5.4	0.0	0.0
Ellendale	1,457	10	56	28.41	29.96	.....	62.4	.....	87	8	72	39	2	52	31	58	55	77	3.45	.....	15	8,614	ne.	49	n.	8	2	13	15	6.9	0.0	0.0
Grand Forks	835	12	89	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.0	0.0
Williston	1,878	41	48	27.95	29.90	+.04	62.8	−0.7	90	8	74	37	4	52	33	54	48	62	3.50	−0.1	12	6,000	se.	38	w.	23	11	15	4	4.8	0.0	0.0
Upper Mississippi Valley.							71.7	+0.7										65	4.06	−0.3										4.9		
Minneapolis	918	102	208	28.95	29.92	.....	68.4	.....	94	13	77	45	5	59	27	.....	.....	.....	8.43	+4.4	13	6,755	se.	55	nw.	8	5	10	15	6.6	0.0	0.0
St. Paul	837	236	261	29.05	29.94	+.02	68.0	+0.6	93	12	77	45	5	59	28	.....	.....	.....	7.76	+3.4	14	6,992	se.	40	se.	26	7	16	7	5.5	0.0	0.0
La Crosse	714	11	48	29.19	29.94	+.01	70.0	+1.8	95	12	80	46	3	60	33	.....	.....	.....	8.14	+3.7	11	2,821	se.	21	sw.	28	9	10	11	6.0	0.0	0.0
Madison	974	70	78	28.96	29.98	+.04	69.0	+1.7	90	13	78	49	17	60	22	61	57	68	5.62	+1.5	11	5,617	sw.	44	ne	13	4	15	11	6.1	0.0	0.0
Wausau	1,247	4	.....	28.79	29.94	.....	73.1	.....	96	13	82	50	5	64	25	64	60	67	2.62	−2.4	9	6,037	s.	30	nw.	21	11	12	7	5.0	0.0	0.0
Charles City	1,015	10	49	28.90	29.96	+.05	69.2	+0.4	95	13	80	43	5	58	29	62	58	69	4.43	−9.7	14	4,512	sw.	26	s.	25	10	17	3	5.0	0.0	0.0
Davenport	606	71	79	29.33	29.98	+.04	72.3	+1.4	93	13	82	51	17	62	26	63	58	62	2.54	−1.6	6	5,073	sw.	26	sw.	1	11	14	5	4.5	0.0	0.0
Des Moines	861	84	97	29.06	29.95	+.03	72.5	+2.1	95	13	82	50	5	63	25	63	58	61	1.25	−3.7	9	6,190	sw.	32	sw.	28	4	18	8	6.1	0.0	0.0
Dubuque	698	81	96	29.25	29.99	+.06	70.9	+1.3	95	13	81	50	17	61	26	62	58	67	5.24	+0.7	10	3,970	s.	22	nw.	1	7	17	6	5.5	0.0	0.0
Keokuk	614	64	78	29.33	30.00	+.06	73.4	+0.9	94	28	83	55	6	64	24	64	58	61	2.99	−1.4	6	5,063	s.	26	w.	16	12	12	6	4.7	0.0	0.0
Cairo	356	87	93	29.63	30.00	+.03	74.5	−0.7	94	14	83	56	18	66	25	66	61	67	2.10	−2.2	5	5,081	sw.	33	sw.	16	13	9	8	4.8	0.0	0.0
Peoria	609	11	45	29.34	30.00	+.05	72.0	−1.1	96	28	83	48	18	60	30	64	59	66	2.18	−2.1	7	4,159	sw.	19	sw.	16	20	8	2	2.7	0.0	0.0
Springfield, Ill	644	10	91	29.32	29.98	+.03	72.8	+0.5	95	28	84	49	4	62	27	63	59	65	3.89	−0.4	4	5,398	sw.	26	w.	16	12	9	9	4.8	0.0	0.0
Hannibal	534	74	109	29.43	29.99	+.04	72.8	−0.5	94	28	83	50	6	63	29	.....	.....	.....	2.21	−1.3	7	6,169	sw.	34	nw.	1	14	13	3	4.1	0.0	0.0
St. Louis	567	265	303	29.40	29.99	+.04	75.2	+0.1	94	16	84	57	18	66	23	63	57	57	1.53	−2.9	6	8,512	sw.	39	sw.	22	13	14	3	3.6	0.0	0.0
Missouri Valley.							70.9	0.0										68	3.49	−0.8										4.8		
Columbia, Mo	781	11	84	29.17	29.99	+.04	72.8	−1.7	94	28	83	53	6	62	30	.....	.....	.....	1.49	−2.9	7	5,132	s.	26	sw.	16	14	10	6	4.1	0.0	0.0
Kansas City	963	161	181	28.96	29.97	+.05	73.2	+0.2	93	27	82	54	5	64	24	64	58	62	6.63	+2.0	9	8,381	s.	52	ne.	8	15	11	4	3.6	0.0	0.0
St. Joseph	967	11	49	28.94	29.95	.....	73.4	.....	94	13	83	50	5	64	29	64	58	63	6.51	.....	7	6,014	s.	30	nw.	16	17	9	4	3.7	0.0	0.0
Springfield, Mo	1,324	98	104	28.63	30.01	+.06	71.8	−0.5	90	16	80	55	5	63	24	63	58	65	1.43	−3.8	6	6,568	s.	32	sw.	16	16	9	5	3.6	0.0	0.0
Iola	984	11	50	28.95	29.97	+.04	73.0	−0.4	93	29	84	47	5	62	34	.....	.....	.....	3.59	−1.1	6	4,708	s.	21	ne.	8	17	7	6	4.0	0.0	0.0
Topeka	987	92	107	.....	.....	.....	73.0	−0.5	96	15	84	48	5	62	32	.....	.....	.....	3.43	−1.4	10	7,804	s.	36	s.	29	14	11	5	3.8	0.0	0.0
Drexel	1,299	10	53	28.56	29.93	.....	70.4	.....	92	13	80	43	5	61	31	63	59	70	2.16	.....	9	8,359	s.	41	sw.	28	9	14	7	5.2	0.0	0.0
Lincoln	1,189	11	84	28.69	29.92	+.02	73.0	+1.4	96	13	83	48	5	62	32	63	57	62	2.05	−2.3	7	7,975	s.	42	se.	25	11	11	8	5.0	0.0	0.0
Omaha	1,105	115	122	28.79	29.94	+.03	73.1	+1.5	96	13	82	50	5	64	25	64	60	67	2.62	−2.4	9	6,037	s.	30	nw.	21	11	12	7	5.0	0.0	0.0
Valentine	2,598	47	54	27.26	29.93	+.07	66.3	−0.8	98	8	77	40	2	56	35	59	54	72	3.48	−0.3	18	6,546	s.	39	se.	5	5	18	7	5.7	0.0	0.0
Sioux City	1,135	94	164	28.74	29.93	+.03	71.5	+2.1	95	13	80	49	2	62	23	62	58	67	3.06	−0.8	11	8,884	s.	72	sw.	8	9	10	11	5.6	0.0	0.0
Huron	1,306	59	74	28.56	29.94	+.06	66.7	+0.1	93	12	76	44	4	57	28	61	57	74	6.27	+2.5	15	6,823	se.	52	nw.	30	10	12	8	5.0	0.0	0.0
Pierre	1,572	70	75	28.27	29.91	+.04	66.6	−2.3	98	8	76	42	4	57	32	61	59	79	4.12	+1.0	13	5,157	e.	38	se.	24	8	8	14	5.9	0.0	0.0
Yankton	1,233	49	57	28.61	29.90	+.02	69.8	+0.4	92	26	79	47	2	60	31	.....	.....	.....	3.75	−0.5	15	5,498	w.	35	sw.	8	7	7	16	6.5	0.0	0.0

TABLE I.—*Climatological data for Weather Bureau Stations, June, 1920.*

Districts and stations.	Elevation of instruments.			Pressure.			Temperature of the air.										Mean wet thermometer.	Mean temperature of the dew-point.	Mean relative humidity.	Precipitation.			Wind.					Clear days.	Partly cloudy days.	Cloudy days.	Average cloudiness, tenths.	Total snowfall.	Snow, sleet, and ice on ground at end of month.
	Barometer above sea level.	Thermometer above ground.	Anemometer above ground.	Station, reduced to mean of 24 hours.	Sealevel, reduced to mean of 24 hours.	Departure from normal.	Mean max. + mean min. ÷ 2.	Departure from normal.	Maximum.	Date.	Mean maximum.	Minimum.	Date.	Mean minimum.	Greatest daily range.					Total.	Departure from normal.	Days with 0.01 inch or more.	Total movement.	Prevailing direction.	Maximum velocity: Miles per hour.	Maximum velocity: Direction.	Maximum velocity: Date.						
	Ft.	Ft.	Ft.	In.	In.	In.	° F.	° F.	° F.		° F.	° F.		° F.	° F.	° F.	° F.	%	In.	In.		Miles.									0-10	In.	In.
Northern Slope.							**60.0**	**− 1.7**										**60**	**1.83**	**− 0.4**											**4.9**		
Billings	3,140	5																															
Havre	2,505	11	44	27.31	29.91	+ .06	61.8	− 0.6	87	22	74	34	1	49	37	52	45	61	3.09	+ 0.3	12	4,329	sw.	60	sw.	22	14	14	2	3.8	0.0	0.0
Helena	4,110	87	112																														
Kalispell	2,973	48	56	26.90	29.93	+ .04	55.6	− 3.2	86	30	68	36	26	44	40	46	37	60	0.95	− 0.8	12	4,004	nw.	35	sw.	13	11	12	7	4.7	0.0	0.0
Miles City	2,371	26	48																														
Rapid City	3,259	50	58	26.59	29.96	+ .11	62.4	− 1.4	94	8	72	40	2	53	39	54	48	62	4.13	+ 0.5	18	5,578	n.	44	nw.	23	6	12	12	5.9	0.0	0.0
Cheyenne	6,088	84	101	24.04	29.90	+ .06	59.4	− 2.1	84	8	71	35	1	48	36	50	43	63	0.70	− 0.9	10	7,448	s.	52	w.	5	5	13	12	6.4	0.0	0.0
Lander	5,372	60	68	24.64	29.91	+ .06	60.4	− 0.9	86	7	75	31	1	45	41	46	35	46	0.37	− 0.7	4	3,501	w.	33	sw.	29	14	12	4	4.4	0.0	0.0
Sheridan	3,790	10	47	26.08	29.93		60.8		91	8	74	31	4	48	44	52	45	61	1.88	0.0	10	3,953	nw.	34	nw.	23	12	10	8	4.7	0.0	0.0
Yellowstone Park	6,200	11	48	23.89	29.93	+ .07	52.0	− 4.0	77	22	65	24	1	39	36	42	34	57	1.18	− 0.5	12	5,461	s.	38	sw.	10	8	13	9	5.3	0.2	0.0
North Platte	2,821	11	51	27.07	29.95	+ .09	68.4	0.0	95	11	80	43	4	57	34	59	55	69	2.35	− 0.9	11	4,992	e.	31	n.	24	15	8	7	4.3	0.0	0.0
Middle Slope.							**71.4**	**− 0.1**										**64**	**1.65**	**− 1.5**											**4.6**		
Denver	5,292	106	113	24.75	29.91	+ .07	65.7	− 0.7	90	24	77	44	1	54	36	52	43	53	0.65	− 0.8	12	5,424	s.	35	n.	3	6	14	10	6.3	0.0	0.0
Pueblo	4,685	80	86	25.29	29.89	+ .06	68.4	− 0.6	95	24	82	46	20	54	40	54	44	51	0.47	− 1.0	9	4,494	se.	39	w.	17	7	14	9	5.9	0.0	0.0
Concordia	1,392	50	58	28.50	29.94	+ .04	73.3	+ 0.6	95	29	84	45	5	63	34	63	57	62	0.84	− 4.1	7	7,142	s.	27	s.	25	7	18	5	5.3	0.0	0.0
Dodge City	2,509	11	51	27.39	29.94	+ .07	72.6	+ 0.5	98	25	84	49	20	61	34	62	56	63	2.08	− 1.2	12	8,656	s.	32	sw.	28	18	7	5	3.5	0.0	0.0
Wichita	1,358	139	158	28.55	29.96	+ .05	73.6	+ 0.7	97	15	83	52	5	64	27	64	60	68	3.76	− 1.0	7	10,317	s.	38	s.	29	18	9	3	3.6	0.0	0.0
Altus	1,410	5							100	30	90	55	20	65	37				1.81		7		se.				18	4	8		0.0	0.0
Broken Arrow	765	11	52	29.16	29.98		73.4		96	30	84	55	6	63	29	67	64	74	1.62		8	8,494	s.	41	sw.	16	18	6	6	4.0	0.0	0.0
Muskogee	652	4					74.4		100	9	88	54	27	61	40				3.70		6		e.				18	4	8		0.0	0.0
Oklahoma	1,214	10	47	28.72	29.97	+ .06	74.6	− 1.1	96	30	84	56	5	65	30	66	63	70	2.08	− 1.0	9	9,002	s.	38	n.	1	17	8	5	3.7	0.0	0.0
Southern Slope.							**75.6**	**− 1.5**										**63**	**2.11**	**− 0.6**											**4.2**		
Abilene	1,738	10	52	28.16	29.93	+ .05	77.4	− 0.8	95	17	88	60	19	66	31	67	62	64	1.77	− 1.4	8	7,285	s.	39	e.	17	15	9	6	4.2	0.0	0.0
Amarillo	3,676	10	49	26.28	29.93	+ .08	72.4	+ 0.4	97	16	85	52	20	60	34	62	56	66	2.56	− 0.4	10	8,508	se.	37	w.	18	12	18	0	4.3	0.0	0.0
Del Rio	944	64	71	28.95	29.92	+ .07	79.8	− 2.3	94	19	90	63	21	70	29				1.91	− 0.5	6	7,987	se.	45	nw.	4	13	15	2	3.9	0.0	0.0
Roswell	3,566	75	85	26.34	29.87	+ .07	72.9	− 3.4	96	7	86	53	5	59	39	60	53	59	2.19	+ 0.1	10	5,584	s.	40	nw.	22	7	21	2	4.6	0.0	0.0
Southern Plateau.							**73.2**	**− 1.4**										**37**	**0.65**	**+ 0.3**											**2.6**		
El Paso	3,762	110	133	26.14	29.80	+ .05	77.4	− 2.2	100	22	90	57	4	64	33	59	47	44	0.99	+ 0.4	7	7,336	se.	46	se.	24	15	14	1	3.4	0.0	0.0
Santa Fe	7,013	57	66	23.29	29.82	+ .01	63.6	− 2.6	83	24	76	45	20	52	33	49	37	44	2.04	+ 1.0	12	5,116	e.	30	se.	2	12	9	9	5.0	0.0	0.0
Flagstaff	6,908	8	57	23.38	29.82	+ .04	57.2	− 2.1	84	21	74	32	1	40	45	43			0.01		1		nw.	32	sw.	23	27	3	0		0.0	0.0
Phoenix	1,108	76	81	28.63	28.75	+ .01	84.4	0.0	110	21	100	61	1	68	39	61	42	28	T.	− 0.1	0	4,243	e.	28	se.	12	24	4	2	1.5	0.0	0.0
Yuma	141	9	54	29.60	29.74	.00	85.2	+ 0.5	112	21	101	63	13	69	40	64	50	38	T.	0.0	0	3,986	sw.	24	se.	26	30	0	0	0.3	0.0	0.0
Independence	3,957	9	41	25.88	29.84	+ .06	71.1	− 2.3	97	21	86	46	29	57	36	51	33	30	0.20	+ 0.1	2	4,903	nw.	25	se.	13	19	7	4	2.9	0.0	0.0
Middle Plateau.							**64.7**	**− 1.0**										**36**	**0.63**	**+ 0.2**											**3.5**		
Reno	4,532	74	81	25.42	29.86	.00	61.2	+ 0.2	91	20	77	34	1	46	42	46	35	46	1.94	+ 1.7	3	5,506	w.	34	w.	7	19	5	6	3.2	0.0	0.0
Tonopah	6,090	12	20	24.03	29.83		64.9		91	21	77	43	29	53	29	46	27	29	0.21	− 0.2	2	6,436	se.	34	w.	20	15	14	1	3.5	0.0	0.0
Winnemucca	4,344	18	56	25.56	29.89	+ .01	62.1	− 1.2	94	21	79	31	1	46	44	46	32	42	0.51	− 0.1	3	4,829	sw.	26	sw.	12	15	7	8	4.2	0.0	0.0
Modena	5,479	10	43	24.58	29.83	+ .01	62.0	− 1.2	89	22	78	38	12	46	45	44	24	30	0.59	+ 0.2	3	9,292	sw.	49	sw.	21	21	8	1	2.2	0.0	0.0
Salt Lake City	4,360	163	203	25.56	29.85	00	68.0	− 0.3	88	22	79	40	1	57	31	51	37	36	0.15	− 0.6	4	6,099	nw.	46	nw.	22	17	7	6	3.6	0.0	0.0
Grand Junction	4,602	60	68	25.33	29.85	+ .02	70.2	− 2.4	92	22	84	46	2	57	37	51	36	34	0.39	0.0	3	5,492	se.	40	se.	26	12	12	6	4.4	0.0	0.0
Northern Plateau.							**62.0**	**− 3.0**										**50**	**0.96**	**− 0.2**											**4.9**		
Baker	3,471	48	53	26.43	29.99	+ .04	56.2	− 2.4	88	21	69	30	1	43	42	47	40	61	0.70	− 0.5	10	4,029	nw.	27	se.	14	7	12	11	5.4	0.0	0.0
Boise	2,739	78	86	27.10	29.92	+ .01	64.1	− 1.9	96	21	78	35	1	50	41	52	43	52	1.18	+ 0.3	5	3,854	nw.	25	nw.	5	12	14	4	4.1	0.0	0.0
Lewiston	757	40	48	29.17	29.98	+ .04	63.2	− 5.9	96	30	77	40	2	49	43				1.26	+ 0.2	10	2,375	e.	26	n.	27	10	10	10	5.6	0.0	0.0
Pocatello	4,477	60	68	25.43	29.88	+ .01	62.4	− 1.8	88	21	76	29	1	49	39	48	34	41	0.95	0.0	6	5,489	se.	36	sw.	5	11	11	8	4.9	0.0	0.0
Spokane	1,929	101	110	27.94	29.97	+ .03	60.8	− 2.6	92	30	73	39	26	48	29	49	39	52	0.65	− 1.0	6	5,316	sw.	42	s.	21	12	14	4	4.3	0.0	0.0
Walla Walla	991	57	65	28.91	29.98	+ .02	65.0	− 3.2	96	21	77	45	2	53	37	52	40	46	1.03	− 0.2	5	3,502	s.	19	w.	14	13	8	9	4.9	0.0	0.0
North Pacific Coast Region.							**57.8**	**− 0.7**										**73**	**1.96**	**− 0.1**											**5.8**		
North Head	211	11	56	29.84	30.07	+ .08	52.9	− 2.1	64	2	56	44	1	50	16	50	48	85	1.69	− 0.1	12	11,983	nw.	60	se.	16	5	13	12	6.2	0.0	0.0
Port Angeles	29	8	53	30.05	30.08		53.9		77	3	62	37	1	45	33				0.82	− 0.5	10	4,564	nw.	30	nw.	22	6	11	13	6.5	0.0	0.0
Seattle	125	215	250	29.92	30.06	+ .06	58.6	− 1.5	81	3	67	43	1	50	27	52	47	70	1.93	+ 0.2	13	5,733	n.	33	sw.	8	5	11	14	6.6	0.0	0.0
Tacoma	213	113	120	29.82	30.05	+ .02	58.6	− 0.8	84	3	68	44	23	50	34	53	48	73	1.76	− 0.4	11	4,166	n.	23	sw.	8	4	14	12	6.5	0.0	0.0
Tatoosh Island	86	7	57	29.95	30.05	+ .03	52.4	− 0.6	64	3	56	46	1	49	16	50	49	80	4.42	+ 0.2	18	8,852	s.	55	s.	8	5	10	15	6.4	0.0	0.0
Yakima	1,071	4																															
Medford	1,425	4					63.8		96	20	80	36	1	48	48				1.81		6		nw.				10	8	12		0.0	0.0
Portland, Oreg.	153	68	106	29.88	30.04	.00	62.1	− 0.8	87	3	72	43	23	52	33	53	46	61	2.11	+ 0.3	10	4,279	nw.	20	n.	21	10	10	10	5.3	0.0	0.0
Roseburg	510	9	57	29.49	30.03	.00	62.4	+ 1.5	90	30	76	40	1	49	42	53	45	62	0.96	− 0.1	6	2,874	n.	18	n.	26	16	9	5	3.4	0.0	0.0
Middle Pacific Coast Region.							**62.5**	**+ 0.1**										**63**	**0.52**	**+ 0.1**											**3.3**		
Eureka	62	73	89	29.98	30.05	.00	54.3	− 0.3	70	6	60	42	1	49	25	51	49	86	1.92	+ 0.9	4	6,059	n.	37	n.	26	11	8	11	5.2	0.0	0.0
Mount Tamalpais	2,375	11	18	27.49	29.94	− .01	60.3	− 3.8	91	19	67	45	6	53	23	51	43	60	0.24	− 0.2	2	16,118	nw.	80	nw.	3	20	6	4	2.9	0.0	0.0
Point Reyes Light	490	7	18	29.39	29.91		53.4	+ 0.6	78	20	58	47	2	49	26				1.16		3	18,775	nw.	72	nw.	9	10	12	8	5.0	0.0	0.0
Red Bluff	332	50	56	29.51	29.86	− .02	74.8	− 0.9	107	20	87	55	6	62	38	57	42	39	0.67	+ 0.2	2	5,548	se.	37	nw.	26	22	6	2	2.7	0.0	0.0
Sacramento	69	106	117	29.80	29.87	− .02	70.2	+ 1.3	108	20	84	50	10	56	41	57	46	51	0.05	− 0.1	2	6,569	s.	26	nw.	26	24	5	1	2.2	0.0	0.0
San Francisco	155	208	243	29.77	29.94	− .02	60.2	+ 3.2	92	19	68	49	5	53	32	54	51	79	0.04	− 0.1	1	9,990	sw.	38	w.	10	19	7	4	3.0	0.0	0.0
San Jose	141	12	110	29.81	29.96		64.4	− 0.6	101	19	79	44	1	50	47				0.21	+ 0.1	2	4,965	nw.	31	sw.	28	24	5	1	2.1	0.0	0.0
South Pacific Coast Region.							**66.5**	**− 0.2**										**67**	**0.02**	**0.0**											**3.2**		
Fresno	327	89	98	29.51	29.86	+ .01	74.9	− 0.9	110	20	90	52	10	60	38	57	40	37	0.03	− 0.1	2	6,701	nw.	29	nw.	5	23	6	1	1.5	0.0	0.0
Los Angeles	338	159	191	29.57	29.93	+ .03	65.8	− 0.9	82	18	73	55	29	58	22	59	56	78	T.	− 0.1	0	4,262	sw.	20	sw.	28	15	12	3	3.7	0.0	0.0
San Diego	87	62	70	29.83	29.92	.00	63.6	− 0.2	71	9	68	57	12	59	12	58	56	78	0.02	0.0	2	4,986	sw.	18	w.	16	13	15	2	4.4	0.0	0.0
San Luis Obispo	201	32	40	29.74	29.96	+ .01	61.8	+ 1.4	99	19	73	40	10	50	40	53	49	74	0.05	0.0	2	3,453	nw.	18	w.	17	20	6	4	3.3	0.0	0.0
West Indies.																																	
San Juan, P. R.	82	8	54	29.93	30.02		79.4		92	12	85	71	30	74	16				5.31	− 0.6	16	8,470	e.	42	e.	23	6	16	8	6.0	0.0	0.0
Panama Canal.																																	
Balboa Heights	118	7	97	29.70	29.83	− .01	80.6	+ 0.5	92	19	87	72	6	74	17	75	74	84	4.83	− 2.6	16	3,515	nw.	22	nw.	23	0	11	19	7.7	0.0	0.0
Colon	36	7	97	29.79	29.83	− .01	81.4	+ 1.4	91	17	87	73	3	76	18	76	75	84	13.29	− 0.1	26	5,296	w.	22	w.	23	1	4	25	8.6	0.0	0.0
Alaska.																																	
Juneau	80	11	49				53.2		78	9	61	41	19	45	34	49	45	74	4.90		17	2,625	se.	17	se.	17	4	5	21	8.0	0.0	0.0

TABLE II.—*Accumulated amounts of precipitation for each 5 minutes, for the principal storms in which the rate of fall equaled or exceeded 0.25 inch in any 5 minutes, or 0.80 in 1 hour, during June, 1920, at all stations furnished with self-registering gages.*

Stations.	Date.	Total duration.		Total amount of precipitation.	Excessive rate.		Amount before excessive rate began.	Depths of precipitation (in inches) during periods of time indicated.													
		From—	To—		Began—	Ended—		5 min.	10 min.	15 min.	20 min.	25 min.	30 min.	35 min.	40 min.	45 min.	50 min.	60 min.	80 min.	100 min.	120 min.
Abilene, Tex.	19	D. N. a. m.	D. N. a. m.	0.94	12:56 a. m.	1:19 a. m.	0.01	0.14	0.34	0.55	0.60	0.65									
Albany, N. Y.	29	3:36 p. m.	5:45 p. m.	0.85	3:36 p. m.	3:51 p. m.	0.00	0.38	0.68	0.78											
Alpena, Mich.	10			0.76														0.59			
Amarillo, Tex.	18			0.70														0.57			
Anniston, Ala.	5	12:05 a. m.	3:50 a. m.	0.94	3:22 a. m.	3:38 a. m.	0.35	0.21	0.41	0.54	0.57										
	18	1:25 p. m.	2:46 p. m.	0.98	1:54 p. m.	2:10 p. m.	0.03	0.17	0.58	0.87	0.89										
Asheville, N. C.	20			0.61														0.25			
Atlanta, Ga.	3			0.62														0.45			
Atlantic City, N. J.	17	6:40 p. m.	9:40 p. m.	1.26	6:40 p. m.	7:05 p. m.	0.00	0.14	0.34	0.46	0.67	0.78									
	29	6:24 p. m.	9:45 p. m.	2.81	7:49 p. m.	9:26 p. m.	0.09	0.16	0.43	0.74	0.04	1.32	1.44	1.49	1.56	1.64	1.79	1.81	2.18	2.72	
Augusta, Ga.	4			0.84														0.72			
Baker, Oreg.	17			0.31														0.26			
Baltimore, Md.	13	2:40 p. m.	5:20 p. m.	1.16	3:54 p. m.	4:19 p. m.	0.10	0.25	0.44	0.71	0.88	1.01									
	†24	5:05 p. m.	7:20 p. m.	1.36	5:19 p. m.	6:12 p. m.	0.01	0.08	0.19	0.26	0.34	0.43	0.51	0.59	0.71	0.90	1.17	1.30			
Bentonville, Ark.	16–17	5:45 p. m.	2:15 a. m.	0.98	9:41 p. m.	10:03 p. m.	0.03	0.20	0.50	0.66	0.78	0.87									
Binghamton, N. Y.	29–30	10:20 p. m.	12:30 a. m.	0.81	11:04 p. m.	11:32 p. m.	0.06	0.10	0.24	0.32	0.43	0.56	0.63								
Birmingham, Ala.	20			1.21														0.49			
Bismarck, N. Dak.	25–26			0.54														0.17			
Block Island, R. I.	3			0.60														0.54			
Boise, Idaho.	29			0.84														0.43			
Boston, Mass.	5			2.46														0.47			
Buffalo, N. Y.	2			0.85														0.61			
Burlington, Vt.	15	5:50 a. m.	7:15 a. m.	0.66	6:18 a. m.	6 32 a. m.	0.03	0.19	0.40	0.54											
Cairo, Ill.	2	10:29 a. m.	11:27 a. m.	0.61	10:54 a. m.	11:08 a. m.	0.01	0.18	0.41	0.60											
Canton, N. Y.	29	D. N. a. m.	D. N. a. m.	0.52	12:09 a. m.	12;20 a. m.	0.01	0.23	0.36	0.38											
Charles City, Iowa.	20	5:11 p. m.	6:32 p. m.	1.37	5:20 p. m.	6:00 p. m.	0.06	0.09	0.22	0.48	0.66	0.79	0.99	1.18	1.25						
Charleston, S. C.	5	9:04 a. m.	11:10 a. m.	1.51	9:06 a. m.	10:48 a. m.	0.01	0.15	0.22	0.25	0.27	0.30	0.31	0.38	0.46	0.57	0.63	0.85	1.03	1.46	1.50
Charlotte, N. C.	20			1.11														0.52			
Chattanooga, Tenn.	3–4	3:04 p. m.	8:25 a. m.	2.17	7:42 p. m.	8.05 p. m.	0.68	0.21	0.40	0.49	0.60	0.65									
Cheyenne, Wyo.	29			0.24														0.17			
Chicago, Ill.	29	4:45 p. m.	5:06 p. m.	0.54	4:52 p. m.	4:57 p. m.	0.01	0.53													
Cincinnati, Ohio.	13			0.62														0.42			
Cleveland, Ohio.	16	10:15 a. m.	11:12 a. m.	0.79	10:18 a. m.	10:36 a. m.	0.01	0.41	0.54	0.71	0.76										
Columbia, Mo.	21			0.48														0.47			
Columbia, S. C.	4	1:50 p. m.	2:20 p. m.	0.64	1:56 p. m.	2:11 p. m.	0.01	0.24	0.45	0.62											
Columbus, Ohio.	20			0.75														0.38			
Concord, N. H.	29	1:20 p. m.	1:53 p. m.	0.84	1:31 p. m.	1:45 p. m.	T.	0.35	0.60	0.83											
Concordia, Kans.	29			0.33														0.26			
Corpus Christi, Tex.	†2	D. N. a. m.	4:16 a. m.	0.75	2:35 a. m.	2:50 a. m.	0.09	0.11	0.38	0.55											
Dallas, Tex.	3	11:43 a. m.	5:15 p. m.	1.98	1:41 p. m.	2:26 p. m.	0.13	0.40	0.67	0.83	0.92	1.08	1.26	1.45	1.58	1.63					
	19	12:01 a. m.	11:00 a. m.	1.26	4:00 a. m.	4:15 a. m.	0.09	0.25	0.42	0.50											
Davenport, Iowa.	29			1.34														0.57			
Dayton, Ohio.	2	5:28 p. m.	7:05 p. m.	0.72	5:31 p. m.	6:11 p. m.	0.01	0.05	0.13	0.31	0.41	0.43	0.49	0.57	0.71						
Del Rio, Tex.	20			0.86														0.43			
Denver, Colo.	29			0.11														0.10			
Des Moines, Iowa.	29			0.36														0.32			
Detroit, Mich.	10	4:30 p. m.	6:40 p. m.	1.64	5:17 p. m.	5:54 p. m.	0.20	0.09	0.26	0.58	0.82	1.00	1.16	1.25	1.30						
Devils Lake, N. Dak.	14	10:55 a. m.	11:55 a. m.	2.70	11:00 a. m.	11:42 a. m.	0.01	0.26	0.68	1.15	1.63	2.07	2.40	2.54	2.64	2.66					
		3:12 p. m.	3:40 p. m.	0.60	3:14 p. m.	3:32 p. m.	0.01	0.05	0.29	0.51	0.58										
Dodge City, Kans.	17–18			0.85														*			
Drexel, Nebr.	25			0.91														0.59			
Dubuque, Iowa.	1	7:00 a. m.	7:45 a. m.	0.83	7:03 a. m.	7:25 a. m.	0.02	0.20	0.42	0.55	0.74	0.81									
	14	3:00 a. m.	6:15 a. m.	1.13	3:05 a. m.	3:33 a. m.	T.	0.16	0.26	0.34	0.39	0.48	0.54								
Duluth, Minn.	26–27	4:30 p. m.	D. N. a. m.	1.54	6:52 p. m.	7:22 p. m.	0.28	0.29	0.45	0.54	0.69	0.92	1.04								
Eastport, Me.	30			0.61														0.21			
Elkins, W. Va.	17			0.60														0.29			
Ellendale, N. Dak.	3			0.64														0.27			
El Paso, Tex.	27–28			0.55														0.49			
Erie, Pa.	2			0.71														0.62			
Escanaba, Mich.	1	5:40 p. m.	7:20 p. m.	0.99	5:43 p. m.	6:08 p. m.	0.01	0.36	0.50	0.62	0.72	0.81									
Eureka, Cal.	7			1.52														0.27			
Evansville, Ind.	1	5:50 a. m.	11:45 a. m.	1.56	8:16 a. m.	8:54 a. m.	0.31	0.13	0.21	0.32	0.50	0.61	0.66	0.72	0.77						
	2	5:20 p. m.	6:48 p. m.	1.21	6:03 p. m.	6:41 p. m.	0.03	0.17	0.39	0.65	0.80	0.89	1.03	1.11	1.18						
Flagstaff, Ariz.	27			0.01														*			
Fort Smith, Ark.	2			0.35														0.27			
Fort Wayne, Ind.	14	3:25 p. m.	5:20 p. m.	0.86	3:33 p. m.	3:52 p. m.	0.01	0.19	0.49	0.60	0.73										
Fort Worth, Tex.	18–19	11:14 p. m.	8:40 a. m.	1.50	4:14 a. m.	4:33 a. m.	0.10	0.22	0.56	0.94	1.01										
Fresno, Cal.	15			0.02														0.01			
Galveston, Tex.	2	7:30 a. m.	5:00 p. m.	3.04	9:34 a. m.	10:28 a. m.	0.78	0.08	0.13	0.22	0.26	0.30	0.42	0.56	0.81	1.00	1.14	1.26			
	3	11:31 a. m.	2:00 p. m.	0.92	12:27 p. m.	12:58 p. m.	0.01	0.08	0.21	0.30	0.44	0.56	0.67	0.73							
	11	12:25 p. m.	1:45 p. m.	0.72	1:12 p. m.	1:26 p. m.	0.04	0.18	0.38	0.60											
Grand Haven, Mich.	16	2:16 p. m.	4:16 p. m.	0.67	3:23 p. m.	3:40 p. m.	0.06	0.13	0.30	0.44	0.50										
Grand Junction, Colo.	27			0.31														0.17			
Grand Rapids, Mich.	16			2.23														0.84			
Green Bay, Wis.	10	3:05 p. m.	4:10 p. m.	0.89	3:25 p. m.	3:47 p. m.	0.07	0.19	0.25	0.40	0.65	0.70									
		5:05 p. m.	9:35 p. m.	1.74	8:46 p. m.	9:15 p. m.	1.01	0.18	0.35	0.45	0.57	0.64	0.72								
Greenville, S. C.	4–5	10:00 p. m.	10:10 a. m.	1.93	4:34 a. m.	4:57 a. m.	0.57	0.07	0.22	0.32	0.46	0.52									
	5	5:50 p. m.	6:45 p. m.	1.54	5:58 p. m.	6:35 p. m.	0.01	0.21	0.52	0.69	0.83	1.10	1.33	1.49	1.53						
Hannibal, Mo.	1	8:33 p. m.	9:15 p. m.	0.64	8:53 p. m.	9:00 p. m.	0.01	0.48	0.63												
	29	10:55 a. m.	1:40 p. m.	0.59	11:36 a. m.	11:54 a. m.	0.04	0.11	0.30	0.47	0.51										
Harrisburg, Pa.	17			1.56														0.68			
Hartford, Conn.	29			1.05														0.62			
Hatteras, N. C.	24	7:33 a. m.	10:51 a. m.	0.99	8:28 a. m.	8:50 a. m.	T	0.19	0.42	0.64	0.89	0.92									
Havre, Mont.	16	7:32 p. m.	11:40 p. m.	1.32	8:22 p. m.	8:41 p. m.	0.01	0.10	0.24	0.45	0.51										
Helena, Mont.																					
Houghton, Mich.	27			0.90														0.38			
Houston, Tex.	1	11:29 a. m.	4:36 p. m.	1.32	12:10 p. m.	12:21 p. m.	0.07	0.36	0.59	0.61											
Huron, S. Dak.	30	5:00 p. m.	7:38 p. m.	1.28	5:06 p. m.	5:46 p. m.	0.01	0.18	0.45	0.71	0.87	0.99	1.06	1.11	1.19						
Independence, Calif.	28			0.19														0.06			
Indianapolis, Ind.	13	5:48 p. m.	6:39 p. m.	0.86	6:04 p. m.	6:21 p. m.	0.01	0.21	0.64	0.78	0.81										
	14	6:15 p. m.	10:17 p. m.	0.96	8:54 p. m.	9:15 p. m.	0.09	0.17	0.22	0.55	0.76	0.79									
Iola, Kans.	1	5:05 p. m.	D.N.p.m.	1.42	5:17 p. m.	6:02 p. m.	0.01	0.21	0.43	0.48	0.50	0.54	0.61	0.68	0.75	0.80					
	8	9:10 a. m.	11:05 a. m.	0.86	9:18 a. m.	10:02 a. m.	0.03	0.22	0.32	0.39	0.45	0.51	0.55	0.59	0.66	0.71					
Jacksonville, Fla.	†7	8:00 a. m.	8:10 p. m.	4.60	8:18 a. m.	8:42 a. m.	0.01	0.16	0.34	0.49	0.54	0.59									
					9:22 a. m.	9:48 a. m.	0.65	0.24	0.43	0.53	0.72	0.90	0.93								
					12:03 p. m.	2:00 p. m.	1.77	0.17	0.31	0.43	0.64	0.84	0.97	1.10	1.21	1.36	1.42	1.54	1.78	2.42	2.69
	†20	4:37 p. m.	5:20 p. m.	1.16	4:41 p. m.	5:13 p. m.	0.02	0.23	0.56	0.74	0.77	0.79	1.10	1.14							
Kalispell, Mont.	13			0.14														0.13			
Kansas City, Mo.	8	3:15 a. m.	8:15 a. m.	3.14	4:37 a. m.	5:55 a. m.	0.29	0.17	0.28	0.34	0.50	0.99	1.36	1.48	1.55	1.57	1.86	2.20	2.58		
	29	3:55 p. m.	9:10 p. m.	1.55	5:50 p. m.	6:23 p. m.	0.16	0.21	0.39	0.79	0.93	1.03	1.12	1.16							
Keokuk, Iowa.	1	7:22 p. m.	10:11 p. m.	1.33	7:28 p. m.	8:17 p. m.	0.01	0.23	0.48	0.61	0.62	0.63	0.66	0.72	0.86	1.00	1.08				

* Self-register not in use. † Record partly estimated. ‡ No precipitation occurred during month.

TABLE II.—*Accumulated amounts of precipitation for each 5 minutes, for the principal storms in which the rate of fall equaled or exceeded 0.25 inch in any 5 minutes, or 0.80 in 1 hour, during June, 1920, at all stations furnished with self-registering gages*—Continued.

Stations.	Date.	Total duration. From—	Total duration. To—	Total amount of precipitation.	Excessive rate. Began—	Excessive rate. Ended—	Amount before excessive rate began.	Depths of precipitation (in inches) during periods of time indicated. 5 min.	10 min.	15 min.	20 min.	25 min.	30 min.	35 min.	40 min.	45 min.	50 min.	60 min.	80 min.	100 min.	120 min.
Key West, Fla.	8			0.93														0.76			
Knoxville, Tenn.	4	3:15 p.m.	D.N.p.m.	1.77	6:45 p.m.	7:23 p.m.	0.24	0.12	0.28	0.33	0.43	0.54	0.63	0.68	0.73						
La Crosse, Wis.	15	12:05 a.m.	D.N.a.m.	2.01	12:34 a.m.	1:30 a.m.	0.05	0.07	0.17	0.42	0.77	0.96	1.01	1.04	1.04	1.11	1.14	1.77			
		8:40 p.m.	D.N.p.m.	0.64	8:48 p.m.	9:01 p.m.	0.01	0.28	0.43	0.52											
	28	6:45 p.m.	D.N.p.m.	1.94	6:46 p.m.	7:26 p.m.	0.01	0.29	0.46	0.52	0.69	0.82	0.91	0.99	1.06						
Lander, Wyo.	26			0.22														0.22			
Lansing, Mich.	15-16			2.19														0.42			
Lewiston, Idaho.	14			0.32														0.23			
Lexington, Ky.	2	5:32 p.m.	6:35 p.m.	0.82	5:34 p.m.	6:05 p.m.	0.01	0.17	0.36	0.54	0.62	0.72	0.77	0.81							
Lincoln, Nebr.	7			0.72														0.57			
Little Rock, Ark.	2	D.N.a.m.	D.N.a.m.	1.01	3:28 a.m.	3:59 a.m.	0.35	0.08	0.21	0.28	0.37	0.57	0.64	0.66							
Los Angeles, Calif.	30			T														T			
Louisville, Ky.	4			0.82														0.43			
Ludington, Mich.	15	2:28 p.m.	4:10 p.m.	0.64	3:24 p.m.	3:32 p.m.	0.01	0.33	0.59												
Lynchburg, Va.	3	6:15 p.m.	8:30 p.m.	1.75	6:43 p.m.	7:32 p.m.	0.01	0.15	0.41	0.82	1.08	1.26	1.35	1.45	1.55	1.63	1.67				
Macon, Ga.	5	3:30 p.m.	5:15 p.m.	1.07	4:11 p.m.	4:37 p.m.	0.06	0.16	0.39	0.64	0.85	0.97	1.00								
Madison, Wis.	13-14	9:40 p.m.	7:50 a.m.	2 23	9:44 p.m.	10:50 p.m.	0.01	0.14	0.24	0.40	0.55	0.66	0.69	0.69	0.70	0.71	0.85	1.11	1.33		
Marquette, Mich.	27			0.87														0.48			
Memphis, Tenn.	17			0.67														0.41			
Meridian, Miss.	1	5:55 p.m.	D.N.p.m.	1.14	6:00 p.m.	6:28 p.m.	0.01	0.15	0.35	0.65	0.80	0.95	1.03								
	4	1:05 p.m.	2:00 p.m.	0.65	1:07 p.m.	1:23 p.m.	0.01	0.22	0.40	0.58											
Miami, Fla.	27	4:10 p.m.	5:07 p.m.	0.67	4:34 p.m.	4:48 p.m.	0.06	0.26	0.51	0.60											
	28	12:32 p.m.	2:50 p.m.	0.83	12:35 p.m.	1:09 p.m.	0.01	0.13	0.24	0.35	0.38	0.47	0.63	0.73							
Milwaukee, Wis.	16	12:40 p.m.	D.N.p.m.	2.56	12:53 p.m.	1:58 p.m.	0.02	0.27	0.47	0.61	0.69	0.81	0.96	1.10	1.25	1.47	1.76	2.10	2.78		
Minneapolis, Minn.	1	3:30 a.m.	7:10 a.m.	0.85	5:45 a.m.	6:00 a.m.	0.07	0.32	0.57	0.64											
	26	10:25 p.m.	D.N.p.m.	0.55	10:33 p.m.	10:48 p.m.	0.01	0.13	0.24	0.51											
	28	D.N.p.m.	D.N.a.m.	2.17	12:58 a.m.	2:08 a.m.	0.49	0.13	0.29	0.44	0.62	0.72	0.88	0.93	0.95	1.15	1.40	1.46	1.68		
	30	7:45 p.m.	9:30 p.m.	0.75	8:32 p.m.	8:54 p.m.	0.03	0.24	0.33	0.36	0.52	0.63									
Mobile, Ala.	3-4	9:55 p.m.	D.N.a.m.	0.85	11:29 p.m.	11:45 p.m.	0.06	0.27	0.51	0.69	0.71										
	4	7:02 a.m.	8:10 p.m.	1.12	11:01 a.m.	11:22 a.m.	0.04	0.10	0.33	0.62	0.79	0.82									
	19	7:01 p.m.	D.N.p.m.	2.66	8:15 p.m.	8:53 p.m.	0.19	0.29	0.33	0.47	0.69	1.23	1.64	1.98	2.10						
Modena, Utah.	28			0.47														0.15			
Montgomery, Ala.	19	1:10 p.m.	2:10 p.m.	0.67	1:25 p.m.	1:42 p.m.	0.01	0.25	0.28	0.55	0.66										
	19-20	8:10 p.m.	D.N.a.m.	2.08	11:24 p.m.	12:07 a.m.	0.52	0.07	0.15	0.22	0.39	0.44	0.60	0.99	1.08	1.14					
Moorhead, Minn.	8	5:10 p.m.	5:50 p.m.	0.54	5:14 p.m.	5:27 p.m.	0.01	0.30	0.48	0.52											
	26	11:10 a.m.	4:40 p.m.	2.72	11:22 a.m.	12:52 p.m.	0.08	0.13	0.40	0.72	0.92	1.07	1.29	1.44	1.49	1.57	1.59	1.69	2.07	2.49	
Mount Tamalpais, Calif.	14			0.18														0.01			
Nantucket, Mass.	17-18			0.72														0.28			
Nashville, Tenn.	1	3:35 p.m.	6:35 p.m.	1.09	3:54 p.m.	4:33 p.m.	0.05	0.10	0.22	0.40	0.57	0.69	0.77	0.84	0.89						
New Haven, Conn.	17			1.13														0.60			
New Orleans, La.	1	12:18 p.m.	4:15 p.m.	1.32	12:23 p.m.	12:48 p.m.	0.01	0.27	0.72	1.04	1.15	1.23									
	19-20	12:03 p.m.	D.N.a.m.	3.93	4:25 p.m.	5:25 p.m.	0.63	0.06	0.35	0.71	1.24	1.47	1.65	1.79	2.02	2.16	2.28	2.48			
	24	10:43 a.m.	12:39 p.m.	1.17	11:00 a.m.	11:35 a.m.	0.02	0.05	0.11	0.35	0.53	0.67	0.86	1.02							
New York, N. Y.	† 24	7:28 p.m.	9:40 p.m.	1.34	7:33 p.m.	8:03 p.m.	0.01	0.07	0.23	0.73	0.84	0.93	0.99								
Norfolk, Va.	15	5:55 p.m.	7:40 p.m.	1.37	6:14 p.m.	7:03 p.m.	0.01	0.08	0.28	0.45	0.66	0.91	0.91	0.93	1.08	1.23	1.32				
Northfield, Vt.	15			0.69														0.46			
North Head, Wash.	6			0.38														0.10			
North Platte, Nebr.	24-25	11:37 p.m.	D.N.a.m.	0.82	11:42 p.m.	12:22 a.m.	0.01	0.08	0.25	0.38	0.48	0.54	0.58	0.67	0.74						
Oklahoma, Okla.	1			0.47														0.45			
Omaha, Nebr.	1			1.09														1.03			
Oswego, N. Y.	12			0.56														0.32			
Palestine, Tex.	2	1:06 p.m.	4:25 p.m.	1.08	1:51 p.m.	2:20 p.m.	0.16	0.12	0.37	0.49	0.59	0.67	0.72								
Parkersburg, W. Va.	10			0.60														0.55			
Pensacola, Fla.	19	12:45 a.m.	2:30 a.m.	0.76	2:06 a.m.	2:17 a.m.	0.11	0.18	0.61	0.64											
Peoria, Ill.	29			0.91														0.64			
Philadelphia, Pa.	16	3:22 p.m.	6:10 p.m.	1.14	4:49 p.m.	5:12 p.m.	0.46	0.08	0.16	0.39	0.54	0.61									
	17	5:25 p.m.	8:10 p.m.	1.18	5:28 p.m.	5:51 p.m.	0.01	0.23	0.33	0.57	0.82	0.96									
Phoenix, Ariz.	26			T.														T.			
Pierre, S. Dak.	5			1.24														0.59			
Pittsburgh, Pa.	2	5:20 p.m.	8:10 p.m.	0.74	5:40 p.m.	6:07 p.m.	0.03	0.12	0.28	0.36	0.39	0.46	0.51								
	13	2:00 p.m.	4:00 p.m.	0.85	2:05 p.m.	2:29 p.m.	0.01	0.16	0.44	0.57	0.70	0.76									
Pocatello, Idaho.	28			0.41														0.37			
Point Reyes Light, Calif.	14			1.00														0.15			
Port Angeles, Wash.	14			0.29														0.19			
Port Huron, Mich.	15-16	8:48 p.m.	6:00 a.m.	1.29	9:58 p.m.	10:07 p.m.	0.01	0.38	0.50												
Portland, Me.	21			0.63														0.29			
Portland, Oreg.	14			0.74														0.28			
Providence, R. I.	21			0.65														0 44			
Pueblo, Colo.	17			0.13														0.12			
Raleigh, N. C.	5	7:00 p.m.	9:20 p.m.	1.06	7:59 p.m.	8:18 p.m.	0.03	0.44	0.52	0.68	0.76										
	18	10:32 p.m.	11:30 p.m.	0.66	10:48 p.m.	11:07 p.m.	0.03	0.20	0.31	0.46	0.60										
	20	9:05 p.m.	D. N. p.m.	0.91	9:26 p.m.	9:52 p.m.	0.01	0.17	0.29	0.42	0.65	0.72	0.77								
Rapid City, S. Dak.	29			0.91														0.53			
Reading, Pa.	17	3:47 p.m.	6:20 p.m.	0.90	4:23 p.m.	4:49 p.m.	0.01	0.13	0.23	0.37	0.47	0.55	0.59								
Red Bluff, Calif.	15			0.52														0.41			
Reno, Nev.	29			1.68														0.29			
Richmond, Va.	3-4	3:50 p.m.	D. N. a.m.	2.96	5:08 p.m.	5:56 p.m.	0.02	0.25	0.92	1.53	1.88	2.07	2.18	2.25	2.31	2.39	2.43				
Rochester, N. Y.	2			0.14														0.13			
Roseburg, Oreg.	7			0.78														0.14			
Roswell, N. Mex.	13-14	11:27 p.m.	12:45 a.m.	0.64	11:32 p.m.	11:53 p.m.	0.01	0.06	0.20	0.38	0.58	0.61									
Sacramento, Calif.	29			0.02														0.02			
Saginaw, Mich.	11			0.54														0.46			
St. Joseph, Mo.	8	D. N. a.m.	D. N. a.m.	3.36	2:03 a.m.	3:03 a.m.	0.01	0.12	0 36	0.62	0.78	0.99	1.27	1.55	1.91	2.33	2.60	2.97			
	29	3:03 p.m.	5:20 p.m.	0.82	3:10 p.m.	3:24 p.m.	0.01	0.15	0.60	0.75											
St. Louis, Mo.	21			0.64														0.61			
St. Paul, Minn.	27-28	11:45 p.m.	2:25 a.m.	2.03	1:05 a.m.	2:21 a.m.	0.54	0.08	0.10	0.17	0.35	0.50	0.54	0.61	0.68	0.79	0.84	0.99	1.48		
Salt Lake City, Utah.	16			0.05														0.04			
San Antonio, Tex.	5			0.60														0.53			
San Diego, Calif.	15			0.01														0.01			
Sand Key, Fla.	29			0.33														0.31			
Sandusky, Ohio.	16	4:25 p.m.	7:20 p.m.	1.08	4:55 p.m.	5:33 p.m.	0.07	0.17	0.28	0.39	0.42	0.46	0.51	0.58	0.63						
Sandy Hook, N. J.	30	6:30 p.m.	7:05 p.m.	0.61	6:37 p.m.	6:49 p.m.	T	0.16	0.51	0.61											
San Francisco, Calif.	14			0.04														0.02			
San Jose, Calif.	14			0.20														0.06			
San Luis Obispo, Calif.	14-15			0.05														0.01			
Santa Fe, N. Mex.	27			0.87														0.40			
Sault Ste. Marie, Mich.	12	3:00 a.m.	8:50 a.m.	1.42	4:51 a.m.	5:35 a.m.	0.21	0.07	0.12	0.24	0.33	0.42	0.44	0.56	0.79	0.88					
Savannah, Ga.	2	9:10 a.m.	10:25 a.m.	0.65	9:29 a.m.	9:46 a.m.	0.03	0.18	0.40	0.51	0.55										
	17	4:39 p.m.	5:00 p.m.	0.59	4.41 p.m.	4:52 p.m.	0.01	0.38	0.55	0.57											
	19	7:00 p.m.	8:10 p.m.	0.58	7:02 p.m.	7:15 p.m.	0.01	0.35	0.46	0.51											
	23	5:00 p.m.	11:15 p.m.	2.14	6:05 p.m.	7:11 p.m.	0 05	0.11	0.27	0.34	0.39	0.45	0.54	0.71	0.97	1.20	1.40	1.70	1.90		

* Self-register not in use. † Record partly estimated. ‡ No precipitation occurred during month.

TABLE II.—*Accumulated amounts of precipitation for each 5 minutes, for the principal storms in which the rate of fall equaled or exceeded 0.25 inch in any 5 minutes, or 0.80 in 1 hour, during June, 1920, at all stations furnished with self-registering gages*—Continued.

Stations.	Date.	Total duration. From—	Total duration. To—	Total amount of precipitation.	Excessive rate. Began—	Excessive rate. Ended—	Amount before excessive rate began.	5 min.	10 min.	15 min.	20 min.	25 min.	30 min.	35 min.	40 min.	45 min.	50 min.	60 min.	80 min.	100 min.	120 min.
Scranton, Pa	17	12:45 p.m.	6:02 p.m.	1.58	3:36 p.m.	4:26 p.m.	0.52	0.05	0.14	0.13	0.45	0.51	0.63	0.67	0.73	0.78	0.84				
Seattle, Wash	14			0.44														0.22			
Sheridan, Wyo	18			0.86														0.35			
Shreveport, La	2	9:55 a.m.	4:45 p.m.	1.99	12:44 p.m.	1:01 p.m.	0.45	0.35	0.55	0.64	0.69										
					3:40 p.m.	4:10 p.m.	1.39	0.13	0.21	0.32	0.37	0.42	0.56								
	17–18	9:15 p.m.	4:15 a.m.	2.10	9:59 p.m.	11:00 p.m.	0.01	0.08	0.20	0.34	0.48	0.77	0.83	0.86	0.92	0.99	1.03	1.16	1.22		
Sioux City, Iowa	30	10:15 p.m.	12 midngt.	1.08	10:24 p.m.	10:57 p.m.	0.01	0.23	0.52	0.65	0.73	0.82	0.90	0.96							
Spokane, Wash	7			0.51														0.12			
Springfield, Ill	1	D. N. a. m	6:55 a.m.	1.97	5:20 a.m.	6:10 a.m.	0.31	0.24	0.51	0.78	1.01	1.09	1.19	1.29	1.41	1.52	1.61				
	1–2	9:47 p.m.	D. N. a. m.	1.62	9:50 p.m.	10:31 p.m.	0.01	0.19	0.32	0.37	0.48	0.62	0.78	1.03	1.27	1.29					
Springfield, Mo	29–30			1.08														0.63			
Syracuse, N. Y	3			0.24														0.18			
Tacoma, Wash	14			0.29														0.13			
Tampa, Fla	3	4:02 p.m.	5:00 p.m.	0.54	4:08 p.m.	4:33 p.m.	0.01	0.21	0.34	0.39	0.43	0.50									
	7	D. N. a. m.	1:30 p.m.	1.02	5:56 a.m.	6:16 a.m.	0.01	0.17	0.36	0.48	0.53										
	24	6:00 p.m.	7:30 p.m.	0.73	6:12 p.m.	6:26 p.m.	0.01	0.18	0.62	0.70											
Tatoosh Island, Wash	13			0.88														0.21		1.72	1.96
Taylor, Tex	3	3:50 p.m.	6:45 p.m.	0.70	4:47 p.m.	5:03 p.m.	0.01	0.10	0.37	0.55	0.59										
	18	2:15 a.m.	5:55 a.m.	2.11	2:25 a.m.	4:16 a.m.	0.01	0.07	0.18	0.32	0.39	0.58	0.77	0.87	0.90	0.92	0.95	1.01	1.19		
Terre Haute, Ind	16			0.36														0.32			
Thomasville, Ga	4			0.51														0.36			
Toledo, Ohio	1	1:44 p.m.	3:25 p.m.	0.64	1:54 p.m.	2:07 p m.	0.02	0 09	0 36	0 56											
	16	6:23 p m.	11:00 p m.	1.29	6:23 p.m.	6:42 p.m.	0.00	0.16	0.20	0.34	0.57										
Tonopah, Nev	28			0.13														0.07			
Topeka, Kans	29	4:20 p.m.	7:00 p.m.	1.01	4:40 p.m.	4:50 p.m.	0.01	0.39	0.67												
Trenton, N. J	17–18	5:33 p.m.	D N. a. m.	1.01	5:43 p.m.	5:58 p m.	0.01	0.31	0.63	0.71											
	30	6:35 p.m.	7:15 p.m.	1.70	6:38 p.m.	7:06 p.m.	0.01	0.19	0.50	0.96	1.32	1.62	1.69								
Valentine, Nebr	3			1.17														0.24			
Vicksburg, Miss	19	1:48 p m.	3:50 p.m.	0.92	2:25 p.m.	2:41 p.m.	0.10	0.34	0.66	0.72	0.75										
Walla Walla, Wash	7			0.63														0.25			
Washington, D. C	20–21			1.54														0.43			
Wausau, Wis	13	5:00 p.m.	7:47 p.m.	0.63	5:08 p.m.	5:37 p.m.	0 03	0 10	0.16	0.25	0.35	0.45	0.51								
Wichita, Kans	1	3:35 p.m.	5:30 p.m.	1.30	3:44 p.m.	4:33 p.m.	0.01	0.13	0.31	0.47	0.64	0.75	0.86	0.97	1.01	1.10	1.15				
Williston, N. Dak	23	8:10 p.m.	10:15 p.m.	2.30	8:38 p.m.	9:41 p.m.	0.03	0.14	0.33	0.71	1.10	1.36	1.55	1.66	1.77	1.81	1.84	2.19	2.26		
Wilmington, N. C	5	9:50 a.m.	1:00 p.m.	1.16	11:35 a.m.	11:57 a.m.	0.46	0.25	0.38	0.44	0.54	0.58									
	19	6:55 p.m.	8:41 p.m.	0.71	7:48 p.m.	8:00 p.m.	0.14	0.26	0.50	0.54											
Winnemucca, Nev	29			0.41														0.25			
Wytheville, Va	3	5:15 p.m.	10:15 p.m.	1.52	5:15 p.m.	6:06 p.m.	0.00	0.10	0.42	0.65	0.77	0.92	1.00	1.09	1.12	1.21	1.30	1.33			
	14	2:50 p.m.	3:10 p.m.	0.56	2:53 p.m.	3:05 p.m.	0.02	0.25	0.43	0.50											
Yankton, S. Dak	25			1.40														0.71			
Yellowstone Park, Wyo	18			0.24														0.15			

TABLE III.—*Data furnished by the Canadian Meteorological Service, June, 1920.*

Stations.	Altitude above mean sea level Jan. 1, 1919.	Pressure. Station reduced to mean of 24 hours.	Pressure. Sea level reduced to mean of 24 hours.	Pressure. Departure from normal.	Temperature of the air. Mean max. + mean min. ÷ 2.	Temperature of the air. Departure from normal.	Temperature of the air. Mean maximum.	Temperature of the air. Mean minimum.	Temperature of the air. Highest.	Temperature of the air. Lowest.	Precipitation. Total.	Precipitation. Departure from normal.	Precipitation. Total snowfall.
	Feet.	Inches.	Inches.	Inches.	°F.	°F.	°F.	°F.	°F.	°F.	Inches.	Inches.	Inches.
St. Johns, N. F	125	29.72	29.86	−0.05	51.7	+0.1	62.1	41.4	80	30	1.20	−2.4	0.0
Sydney, C. B. I	48	29.91	29.96	+0.01	55.7	+0.3	66.4	44.9	80	36	2.82	−0.4	0.0
Halifax, N. S	88	29.84	29.94	− .01	57.6	−0.1	68.0	47.2	81	36	4.60	+0.8	0.0
Yarmouth, N. S	65	29.86	29.93	− .02	54.5	−0.5	61.4	47.5	74	42	3.14	+0.4	0.0
Charlottetown, P. E. I	38	29.88	29.92	.00	58.0	+0.6	66.4	49.7	80	38	2.78	+0.1	0.0
Chatham, N. B	28	29.90	29.93	+ .04	59.2	−0.8	69.5	49.0	86	40	5.12	+1.7	0.0
Father Point, Que	20	29.88	29.90	+ .03	53.4	+0.4	62.2	44.7	72	34	1.30	−1.7	0.0
Quebec, Que	296	29.61	29.93	+ .01	62.2	+1.0	72.8	51.7	86	42	4.58	+0.9	0.0
Montreal, Que	187	29.72	29.92	− .02	66.0	+1.1	74.8	57.2	85	48	1.86	−1.7	0.0
Stonecliffe, Ont	489	29.34	29.94	.00	57.4	−4.2	77.9	36.9	90	26	1.59	−1.6	0.0
Ottawa, Ont	236	29.68	29.94	.00	65.6	+0.3	75.9	55.3	87	45	4.03	+1.1	0.0
Kingston, Ont	285	29.65	29.96	− .01	62.9	−0.5	70.7	55.1	80	46	2.51	+0.1	0.0
Toronto, Ont	379	29.56	29.95	− .02	65.7	+2.3	76.0	55.4	93	46	2.89	+0.1	0.0
Cochrane, Ont	930												
White River, Ont	1,244	28.65	29.94	.00	57.0	−1.7	71.4	42.5	85	27	3.52	+1.3	0.0
Port Stanley, Ont	592	29.36	30.00	+ .03	63.7	−0.1	73.0	54.3	84	40	6.10	+3.4	0.0
Southampton, Ont	656	29.27			59.6	−0.8	69.3	50.0	84	42	4.19	+1.8	0.0
Parry Sound, Ont	688	29.34	30.02	+ .06	63.0	+1.3	74.4	51.6	85	40	2.01	−0.4	0.0
Port Arthur, Ont	644	29.29	30.00	+ .06	58.2	+1.8	68.5	48.0	84	35	5.78	+3.0	0.0
Winnepeg, Man	760												
Minnedosa, Man	1,690	28.15	29.94	+ .05	60.1	+0.5	72.6	47.7	86	36	2.23	−0.8	0.0
Le Pas, Man	860												
Qu'Appelle, Sask	2,115	27.68	29.90	+ .03	59.2	−0.7	72.1	46.3	83	34	1.48	−1.9	0.0
Medicine Hat, Alb	2,144	27.57	29.79	− .06	63.2	+1.2	77.0	49.4	88	32	1.48	−1.3	0.0
Moose Jaw, Sask	1,759												
Swift Current, Sask	2,392	27.29	29.86	− .01	60.5	+0.5	73.6	47.5	88	30	2.15	−0.5	0.0
Calgary, Alb	3,428	26.35	29.88	+ .04	56.4	+0.4	71.3	41.4	86	30	1.34	−1.1	0.0
Banff, Alb	4,521	25.36	29.88	+ .04	50.0	−1.5	64.4	35.5	81	28	1.25	−2.1	T.
Edmonton, Alb	2,150	27.59	29.85	+ .01	55.1	−1.8	67.5	42.8	80	29	4.49	+1.6	0.0
Prince Albert, Sask	1,450	28.36	29.92	+ .05	57.8	+0.1	70.9	44.7	82	32	3.64	+1.1	0.0
Battleford, Sask	1,592	28.15	29.88	+ .02	57.7	−1.8	69.9	45.6	83	37	3.22	−0.1	0.0
Kamloops, B. C	1,262	28.71	29.98	+ .11	62.1	−1.7	74.4	49.8	94	40	0.63	−0.8	0.0
Victoria, B. C	230	29.77	30.02	+ .01	55.7	−0.6	63.6	47.9	78	43	1.04	−0.2	0.0
Barkerville, B. C	4,180	25.63	29.92	+ .05	45.8	−4.9	56.9	34.7	72	30	4.76	+1.3	0.5
Triangle Island, B. C	680												
Prince Rupert, B. C	170												
Hamilton, Ber	151	30.00	30.16	+ .04	73.6	−1.4	78.5	68.7	82	63	1.45	−4.5	0.0

SEISMOLOGICAL REPORTS.

W. J. Humphreys, Professor in Charge.

[Weather Bureau, Washington, D. C., Aug. 3, 1920.]

Table I.—*Noninstrumental earthquake reports, June, 1920.*

Day.	Approximate time, Greenwich civil.	Station.	Approximate latitude.	Approximate longitude.	Intensity Rossi-Forel.	Number of shocks.	Duration.	Sounds.	Remarks.	Observer.
		CALIFORNIA.								
1920.	*H. m.*		° ′	° ′			*Sec.*			
June 3	5 55	Kennett	40 45	....	3	2	....	None	Felt by several	J. A. Leslie.
10	10 53	Lakeport	39 03	122 56	3	1	5	Rumbling	Felt by many	A. Hyman, M. Callahan.
16	12 15	Salinas	36 41	121 39	3	1	7	None	do	E. D. Eddy.
		Spreckels	36 38	121 36	5	2	3	Faint	Dishes rattled	S. P. Gleason.
18	10 08	Los Angeles	34 03	118 15	3	1	3	None	Clocks stopped	R. F. Young.
	10 09	Mount Wilson	34 13	118 16	2	1	2	do	Star images oscillated	W. P. Hoge.
	10 10	Avalon	33 15	118 15	3	1	....	do	Clocks stopped	T. M. Polhamus.
21	7 20	Warner Springs	33 15	116 45	....	2	....	do	Felt by several	J. A. Ream.
	20 24	Barstow	34 54	117 02	3	2	2	Faint	Felt by many	E. L. White.
22	2 45	Santa Monica	34 02	118 30	5	1	10	Loud rattling	Felt by several	Nellie Barker.
	2 47	Venice	33 58	118 28	7	5	Several.	Rattling	Felt by many; slight damage	A. W. Pugh.
		Los Angeles	34 03	118 15	8	1	12	None	....	H. B. Hersey.
	2 48	Mount Wilson	34 13	118 16	3	1	5	do	Felt by many	W. P. Hoge.
	2 50	Pasadena	34 05	118 10	3	2	6	do	Felt by several	M. S. Jones.
28	9 01	San Luis Obispo	35 13	120 45	5	1	10	do	Felt by many	J. E. Hissong.

Earthquake data as recorded at the United States Weather Bureau office, Los Angeles, Calif., June, 1920.

June 18, 1920.—A light earthquake occurred at 2:08½ a. m., stopping the office clock.

June 21.—A rather sharp earthquake shock occurred at 6:17 p. m., several small shocks occurring after the first one. Some slight damage resulted in older buildings in the different parts of the city. Inglewood and Hyde Park were more seriously damaged; some business buildings collapsed at these places. Some damage at Venice and other beaches.

June 22.—A slight earthquake occurred at 5 a. m., which was felt at Venice and in Los Angeles. No damage reported. Another light shock occurred at 12:30 p. m. This is said to have caused brick to fall from walls at Inglewood.

June 23.—Light earthquake reported to have occurred at about 4 a. m. and at 5 a. m. by several people. No damage.

June 29.—A slight earthquake felt at 8:08 p. m.

TABLE 2.—*Instrumental Reports, June, 1920.*

[For significance of symbols and abbreviations, and for a description of stations and instruments, see the REVIEW for January, 1920, pp. 62-63.]

ALASKA. *U. S. C. & G. S. Magnetic Observatory, Sitka.*

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1920			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
June 5		P_E	4 33 24					Reported from Formosa; these times are consistent with that distance; NS not in operation.
		S_E	4 43 18					
		L_E	4 59 30		10			
		F_E	5 31 —					

ARIZONA. *U. S. C. & G. S. Magnetic Observatory, Tucson.*

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1920			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
June 2		e_E	22 06 31					Long waves well shown; P and S faint.
		e_N	22 05 05					
		$?_N$	22 06 56					
		L_E	22 07 00	8				
		L_N	22 07 25	8				
		M_E	22 07 29	11	730			
		M_N	22 08 00	11		500		
		C	22 15 —	6				
		F	22 27 —					
4		e_N	15 29 25					
		L_E	15 29 30					
		L_N	15 30 10					
		M_E	15 29 50		10			
		M_N	15 30 40	9		30		
		C	15 32 —	6				End overlaps beginning of next quake.
4		L_E	15 36 45					
		L_N	15 37 30					
		M_E	15 37 20	9	50			
		M_N	15 38 05	9		50		
		C	15 40 —	6				
		F	15 47 —					
5		eP_N	4 39 28					Reported from Formosa.
		eS_E	4 46 27					
		L_E	5 11 03	30				
		M_E	5 16 00	24	40			
		C_E	5 54 —	16				
		F_E	6 12 —	16				
		F_N	4 49 —					
7		eP_E	9 57 48					Probably local; nothing on NS.
		L_E	9 59 04					
		M_E	9 59 30	6	10			
		F_E	10 02 —					
18		eP_E	10 11 29					
		S_E	10 12 07					
		S_N	10 12 01					
		M_E	10 13 27	7	10	5		
		C_E	10 15 —					
		F_E	10 19 —					
		F_N	10 16 —					
22		P_E	2 51 27					Reported from Los Angeles as felt at 2.47; phase recorded as P may be L.
		P_N	2 51 24					
		L_N	2 51 52					
		M_E	2 52 24		40			
		M_N	2 52 14	8		60		
		C_E	2 55 20					
		C_N	3 01 —					

COLORADO. *Sacred Heart College, Denver.*

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1920.			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
June 2		P	22 07 30					P indistinct.
		S_N	22 08 ..					
		L_E	22 09 ..	10-12				
		L_N	22 10 ..	10-12				
		M_E	22 12 ..	10	*2,000			
		M_N	22 10 30	10	*2,000			
		C_E	22 13 ..					
		C_N	22 12 ..					
		F_E	22 16 ..					
		F_N	22 17 ..					
5-6								Activity on E. W. at intervals during day.
15		L_N	13					Visible waves, especially on N. S.
		F_N	13 20 ..					

*Trace amplitude.

DISTRICT OF COLUMBIA. *U. S. Weather Bureau, Washington.*

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1920.			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
June 2		P	22 08 55					
		S?	22 16 20					
		L	22 18 45					
		F	22 38 *ca.*					
4		e	15 38 37					Phases indistinguishable.
		F	16 *ca.*					
5		e	4 40 *ca.*					
		eL	5 12 ..					
		L	5 23 ..	24				
		L	5 30 ..	20				
		L	5 43 ..	16				
		F	6 10 *ca.*					
9		e	11 50 10					Phases indistinguishable.
		F	12 45 *ca.*					Amplitudes very small.
18		e	10 25 35					Phases indistinguishable.
		F	10 36 *ca.*					
21		e	14 15 ..					Phases indistinguishable.
		F	14 30 ..					
22		e?	3 03 10					
		S	3 05 16					
		L	3 06 10					
		F	3 15 00					
26		e?	3 04 15					
		F	3 15 ..					

HAWAII. *U. S. C. & G. S. Magnetic Observatory, Honolulu.*

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1920.			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
June 2		P	22 17 18	17				
		L	22 23 18	17				
		M	22 27 48	16	*900			
		C	22 33 ..	17				
		F	23 43 ..	17				
5		iP	4 33 24	16				Reported from Formosa.
		iS	4 42 24	19				
		eL	4 58 36	17				
		M	5 11 36	17	*11,200			
		C	5 24 ..	16				
		F	8 10 ..	17				
9		P	11 42 24	16				
		iS	11 52 06	16				
		eL	12 07 42	17				
		M	12 17 18	17	*2,600			
		C	12 30 ..	17				
		F	13 12 ..	17				
10		P	2 50 06	17				
		L	3 03 30					
		M	3 21 ..	18	*200			
		C	3 26 ..	18				
		F	3 57 ..	17				
12		P	15 47 42					
		eL	15 52 48					
		M	15 59 ..	16	*200			
		C	16 05 ..	17				
		F	16 32 ..	17				
15		e	3 20 36					
		L	3 30 06	17				Micros obscure beginning.
		M	3 39 36	17	*600			
		C	3 47 ..	17				
		F	4 02 ..	18				

ILLINOIS. *U. S. Weather Bureau, Chicago.*

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1920			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
June 2		P	22 06 54				2,800	
		S	22 11 21					
		L	22 13 38					
		M	22 15 27		*5,500			
		F	23 40 *ca*					
4		P	15 33 40				1,700	
		S	15 36 34					
		L	15 37 35					Merged in succeeding quake.
4		P?	15 42 02					
		S?	15 44 25					
		L						Indeterminate.
		F	16 40 *ca*					

*Trace amplitude.

TABLE 2.—*Instrumental Reports, June, 1920*—Continued.

ILLINOIS. *U. S. Weather Bureau, Chicago*—Continued.

1920			H. m. s.	Sec.	γ	μ	Km.	
June 5		P	4 37 30				6,300	
		S	4 45 20					
		L	4 54 50					
		L	5 08 —	30				
		L	5 22 —	23				
		L	5 27 —	18				
		L	5 45 —	15				
		F	8 *ca*					
9		P	11 51 05					
		S?	11 58 00					
		L?	12 14 00					
		L	12 22 —	25				
		L	12 30 —	22				
		L	12 33 30	16				
		F	14 +					Sheet changed.
18								Record undecipherable because of tangling.
21		P?	14 10 —					Phases indistinguishable.
		F	14 40 *ca*					
22		P	2 57 04				1,400	Los Angeles.
		S	2 59 32					
		L	3 00 25					
		F	3 20 *ca*					
26		P	3 00 10					
		S	3 03 50					
		F	3 20 *ca*					
30		P	4 33 13					
		S	4 40 —					
		L	4 45 33					
		L	4 49 —	22				
		L	4 53 —	15				
		F	5 35 *ca*					

MARYLAND. *U. S. C. & G. S. Magnetic Observatory, Cheltenham.*

1920			H. m. s.	Sec.	μ	μ	Km.	
June 2		P_E	22 18 56					Phases ill-defined.
		P_N	22 18 57					
		M_E	22 30 39	10	10	20		
		C_E	22 33 —	9				
		F_E	22 40 —					
		F_N	22 28 —					
4		e_E	10 47 42					
		e_N	10 46 56					
		M_E	10 58 23		10	10		
		F_E	11 04 —					
		F_N	11 01 —					
5		eP_{EE}	4 41 17					These phases are called P_R to satisfy the distance from Formosa
		P_{RN}	4 40 58					
		eS?	4 48 10					
		e	4 50 49					
		L_E	5 17 35	40				
		L_N	5 16 45					
		M_E	5 38 23	17	50			
		M_N	5 39 36	15		190		
		C_E	5 43 —					
		C_N	5 48 —	16				
		F_E	6 04 —					
		F_N	6 07 —					
22		e_N	3 05 14					Barely perceptible on EW. Reported from Los Angeles, 3,600 km. distant.
		L_N	3 06 05					
		M_N	3 06 24	12		10		
		F_N	3 13 —					

VERMONT. *U. S. Weather Bureau, Northfield.*

1920			H. m. s.	Sec.	μ	μ	Km.	
June 2		e	22 20 45					
		F	22 35 ..					
4		e	15 43 ..					
		F	16					
5		e	4 47 ..					
		eL	5 10 ..					
		L	5 14 ..	40				
		L	5 24 ..	20				
		L	5 29 ..	18				
		F	5 50 ..					

CANADA. *Dominion Observatory, Ottawa.*

1920			H. m. s.	Sec.	μ	μ	Km.	
June 2		e?	22 14 48					Irregular waves of small amplitude. May not be seismic.
		eL?	22 19 30					
			to 35 ..	6				
		F	22 55 ..					
4		P?	4 40 *ca*					A large earthquake; the record was unfortunately spoiled through a fogged sheet.
		S?	4 50 *ca.*					
		L	5 08 ..					

* Trace amplitude.

CANADA. *Dominion Observatory, Ottawa*—Continued.

1920			H. m. s.	Sec.	μ	μ	Km.	
June 9		e_N	11 53 09					No evidence of resolution into phases.
			to 59 ..	6				
		F	12 25 ..					
18		e	10 25 30	4				
			to 37 ..	8				
22		e	3 05 52					
			to 25 ..	6				

CANADA. *Dominion Meteorological Service, Toronto.*

1920			H. m. s.	Sec.	μ	μ	Km.	
June 2		e?	22 01 24					
		L	22 17 48					
		L_E	22 19 18					
		M	22 19 54		*1,000			
		F						Micros.
4		L	15 31 12					
		L	15 37 18		*100			
5		P	4? 36 18				10050?	P minute, and ill defined.
		S	4 47 18					
		L	4 57 24					
		L	5 09 24					
		iL?	5 23 30					
		M	5 24 54		*3,000			
		M	5 26 12		*3,000			
		iL?	5 28 42					
		iL?	5 35 54					
		L_E	5 47 36					
		F	7? 30 48					
9		L	11 56 06		*200			No distinct phases.
		L	12 18 06					
9		L_E	12 46 18					
		L_E	12 50 24					
		M	12 55 36		*400			
		F	13 21 06					
9		e	13 44 12					May not be seismic.
		e	13 57 06		*200			
18		L	10? 27 24		*50			
		L	3 04 54					
22			to 23 54		*100			
30		L_E	4 56 24					
		M	4 58 36		*400			
		F	5 09 18					
30		iL?	5 30 54		*300			May not be seismic.

CANADA. *Dominion Meteorological Service, Victoria.*

1920			H. m. s.	Sec.	μ	μ	Km.	
June 2		P	22 10 27					
		S	22 13 24				1710	
		L	22 16 51					
		M	22 19 48		*2250			
		F	22 37 30					
4		P	15 34 10					
		L	15 39 05					
		M	15 43 01		*200			
		F	15 58 16					
5		P	4 33 13				9800	Probably sub-Pacific, about Guam. P minute. S fairly large.
		S	4 44 02					
		L	5 03 14					
		M	5 23 23		*2750			
		L_E	5 32 11					
		L_E	6 02 47					
		L_E	6 36 05					
		F	7 46 00					
				VERTICAL				
		P	*4 33 18*	*2*			*9360*	
		S	*4 43 46*	*4*				
		L	?					
		M	?	*16*				
7		P or S	4 16 17					
		L	4 17 53					
		M	4 18 42		*100			
		F	4 24 07					
9		P?	11?52 19				3980	
		S	11 58 05					
		L	12 05 29					
		M	12 26 37		*600			
		F	13 44 11					
18		P	10 14 23				1740	Reported at Los Angeles at 10.15 a. m.
		L	10 17 20					
		M	10 19 18		*300			
		F	10 26 11					
22		M	2 59 14		*200			
		F	3 05 11					
30		M	4 37 57		*100			
		F	4 50 44					

* Trace amplitude.

No earthquakes were recorded at the following stations during the month of June, 1920:

CANAL ZONE. *Panama Canal*, Balboa Heights.

Reports for June, 1920, have not been received from the following stations:

ALABAMA. *Spring Hill College*, Mobile.
DISTRICT OF COLUMBIA. *Georgetown University*, Washington.
KANSAS. *University of Kansas*. Lawrence.
MASSACHUSETTS. *Harvard University*, Cambridge.
MISSOURI. *St. Louis University*, St. Louis.
NEW YORK. *Canisius College*, Buffalo; *Cornell University*, Ithaca; *Fordham University*, New York.
PORTO RICO. *U. S. C. & G. S. Magnetic Observatory*, Vieques.

TABLE 3.—*Late reports (instrumental)*.

PORTO RICO. *U. S. C. & G. S. Magnetic Observatory, Vieques:*

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1920			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
May 7		eL_E	22 37 40	35				
		M_E	22 38 50		30			
		C_E	22 46 00	20				
		F_E	22 50 00					
29		P_E	21 24 33					
		P_N	21 24 40					
		F_E	21 28 00		10	10		
		F_N	21 29 00					

CANAL ZONE. *Panama Canal, Balboa Heights.*

Date.	Phase.	Time.	Period T.	A_E	A_N	Distance.	Remarks.
1920.		*H. m. s.*	*Sec.*	μ	μ	*Km.*	
May 7	P_E	17 34 28				172	Direction probably SW.
	S_E	17 34 47					
	S_N	17 34 50					
	M_E	17 34 59		*500			
	M_N	17 35 00			*500		
	F_E	17 36 30					
	F_N	17 37 00					
8	P_E	1 23 42				97ca.	
	P_N	1 23 48					Direction probably SW.
	S_E	1 23 54					
	S_N	1 23 59					
	M_E	1 23 55		*1,000			
	M_N	1 24 00			*1,500		
	F_E	1 26 00					
	F_N	1 27 30					
10	P	13 43 48				97ca.	Direction probably SW.
	S	13 43 59					
	M_E	13 44 03		*800			
	M_N	13 44 02			*1,000		
	F_E	13 46 00					
	F_N	13 46 20					

* Trace amplitude.

TABLE 3.—*Late reports (instrumental)*—Continued.

HAWAII. *U. S. C. & G. S. Magnetic Observatory, Honolulu.*

Date.	Phase.	Time.	Period T.	A_E	A_N	Distance.	Remarks.
1920.		*H. m. s.*	*Sec.*	μ	μ	*Km.*	
May 5	iP	8 48 54	18				
	L	8 52 48	17				
	M	8 54 18	17	*100			Actual maximum (*200) at 8:51:18. Times uncertain on account of irregular motion of paper.
	C	8 56 42	17				
	F	9 16 ..	17				
7	iP	5 52 12	17				
	iS	6 02 24	18				
	L	6 19 30	17				
	M_1	6 26 36	17	*1,100			
	M_2	6 30 48	17	*1,100			
	C	6 43 42	17				
	F	8 13 ..	17				
7	iP	21 41 18	19				
	iS	21 48 30	17				
	L	21 54 48	17				
	M	22 05 00	19	*5,100			
	C	22 27 18	17				
	F	25 12 ..	16				
9	P	8 21 54					
	L	8 24 00	20				
	M	8 30 54	20	*200			
	C	8 39 ..	17				
	F	8 57 ..					
10	iP	19 01 30	17				
	iS	19 10 54	17				
	eL	19 26 42	20				
	M	19 33 18	20	*1,400			
	C	19 45 18	18				
	F	20 42 ..	17				
13	eP	1 58 24	18				
	iS	2 06 42	19				
	L	2 20 24	17				
	M	2 28 36	17	*4,100			
	C	2 38 36	16				
	F	5 32 ..	17				
19	eP	3 33 30					
	L	3 54 00					
	M	3 58 00	17	*200			
	C	4 00 ..	17				
	F	4 18 ..	18				
20	P	7 35 12	17				
	iS	7 42 00	17				
	L	7 49 30	17				
	M	8 01 48	17	*1,200			
	C	8 07 18	17				
	F	10 38 ..	19				
22	L	17 28 00	16				
	M	17 37 00	17	*400			
	C	17 43 00	20				
	F	18 09 ..	17				
26	eP	12 36 48	16				
	S	12 38 48	17				
	eL	12 41 30	19				L uncertain. End obscured by micros.
	M	12 47 48	18	*1,400			
	C	13 12 ..	17				

* Trace amplitude.

Chart I. Hydrographs of Several Principal Rivers, June, 1920.

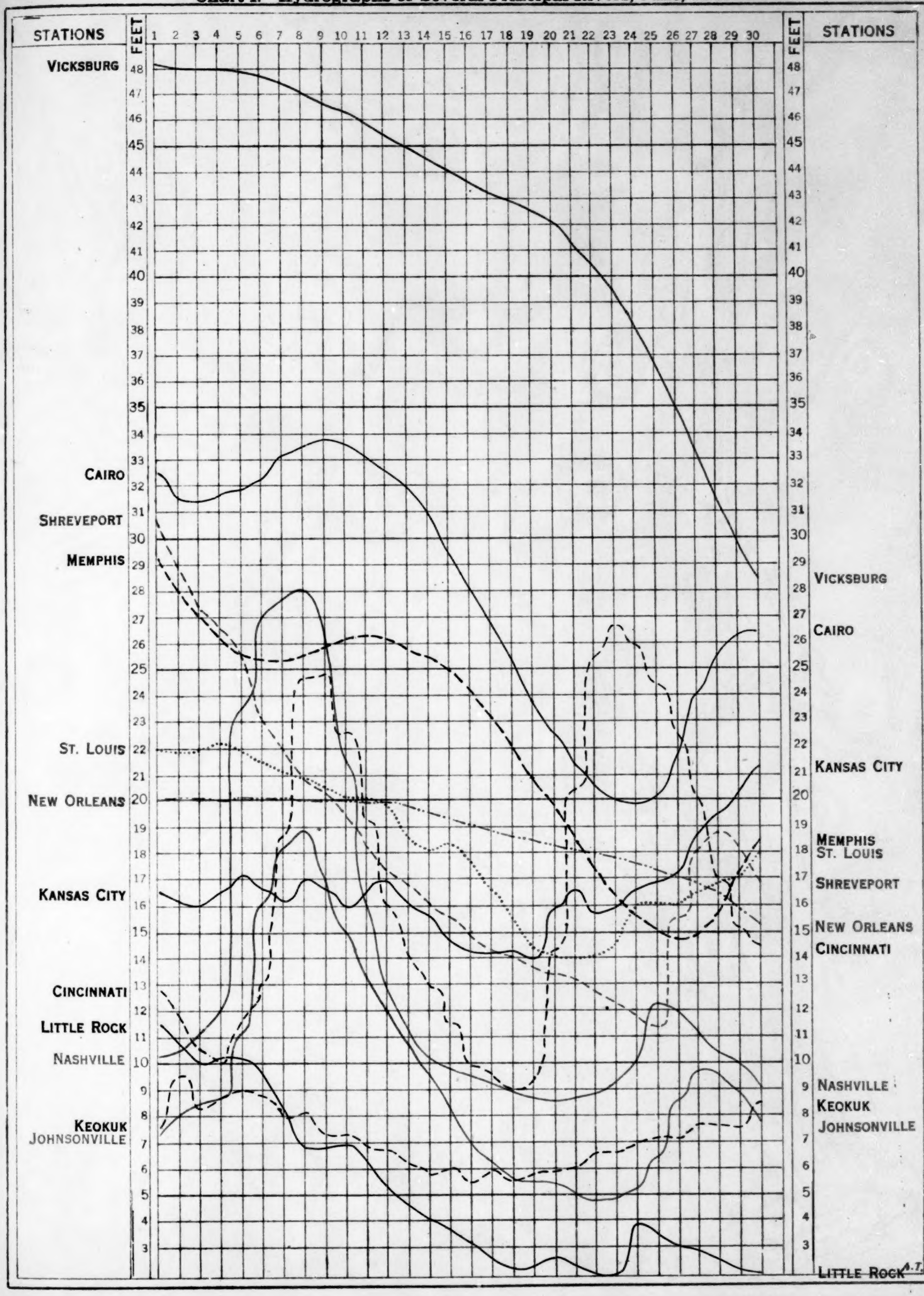

Chart II. Tracks of Centers of High Areas, June, 1920.
(Plotted by R. H. Weightman, Meteorologist.)

Chart III. Tracks of Centers of Low Areas, June, 1920.

Chart III. Tracks of Centers of Low Areas, June, 1920.
(Plotted by R. H. Weightman, Meteorologist.)

Chart IV. Departure (°F.) of the Mean Temperature from the Normal, June, 1920.

Shaded portions show excess (+).
Unshaded portions show deficiency (−).
Lines show amount of excess or deficiency.

Chart V. Total Precipitation, Inches, June, 1920.

Chart VI. Percentage of Clear Sky between Sunrise and Sunset, June, 1920.

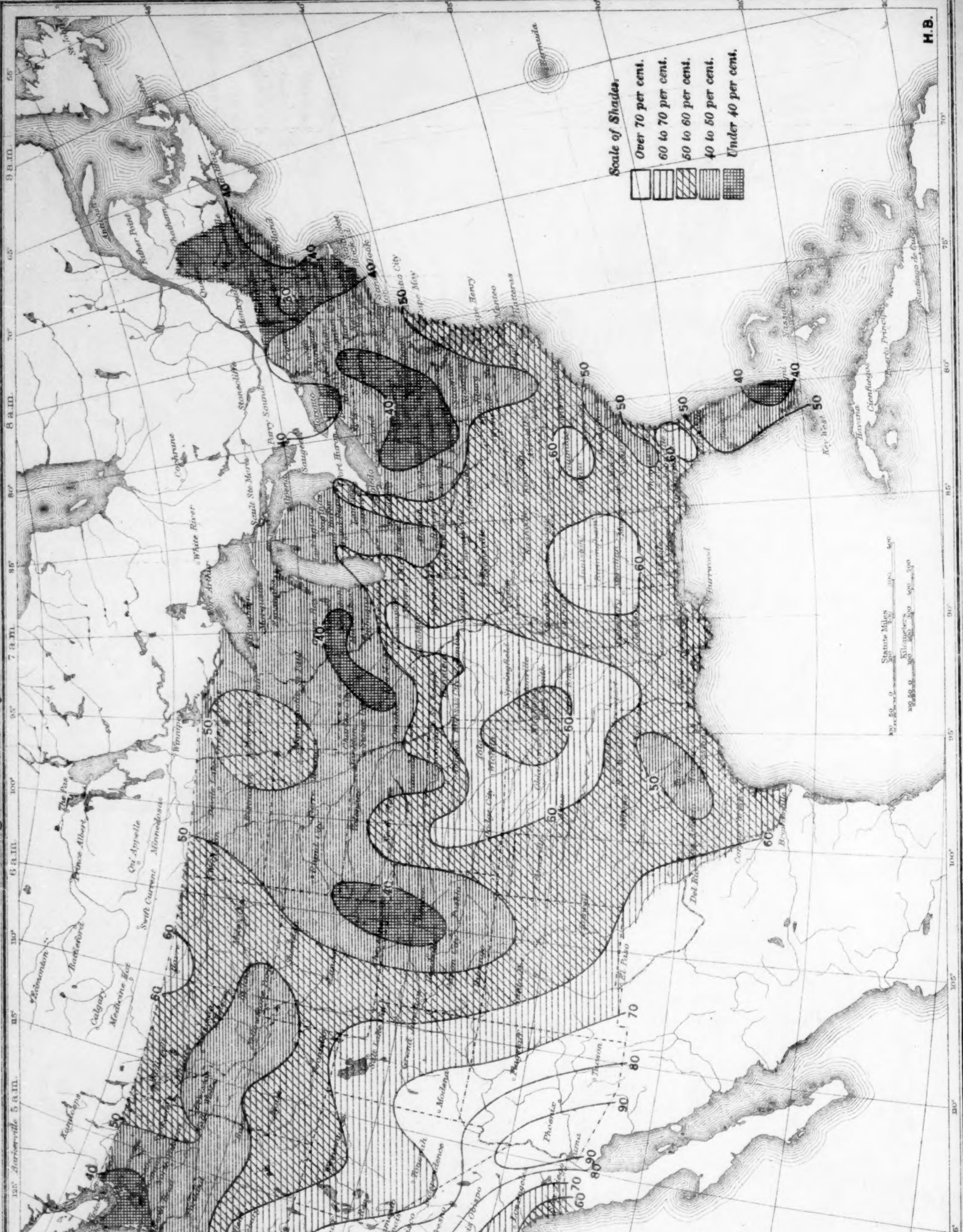

Chart VII. Isobars and Isotherms at Sealevel; Prevailing Winds, June, 1920.

Chart IX. Weather Map of North Atlantic Ocean, June 1, 1920.

(Plotted by F. A. Young.)

Chart IX. Weather Map of North Atlantic Ocean, June 1, 1920.
(Plotted by F. A. Young.)

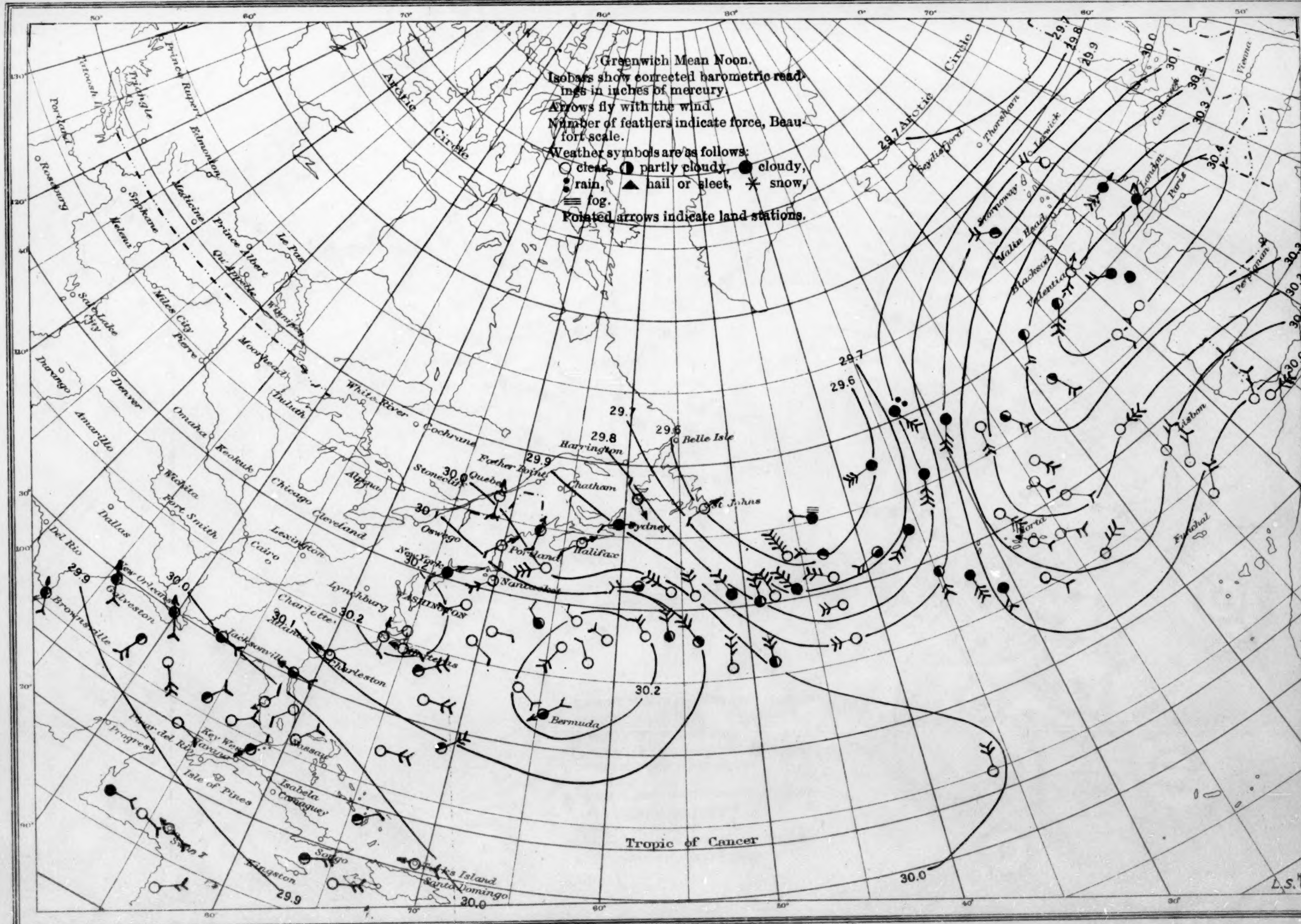

Chart X. Weather Map of North Atlantic Ocean, June 2, 1920.

(Plotted by F. A. Young.)

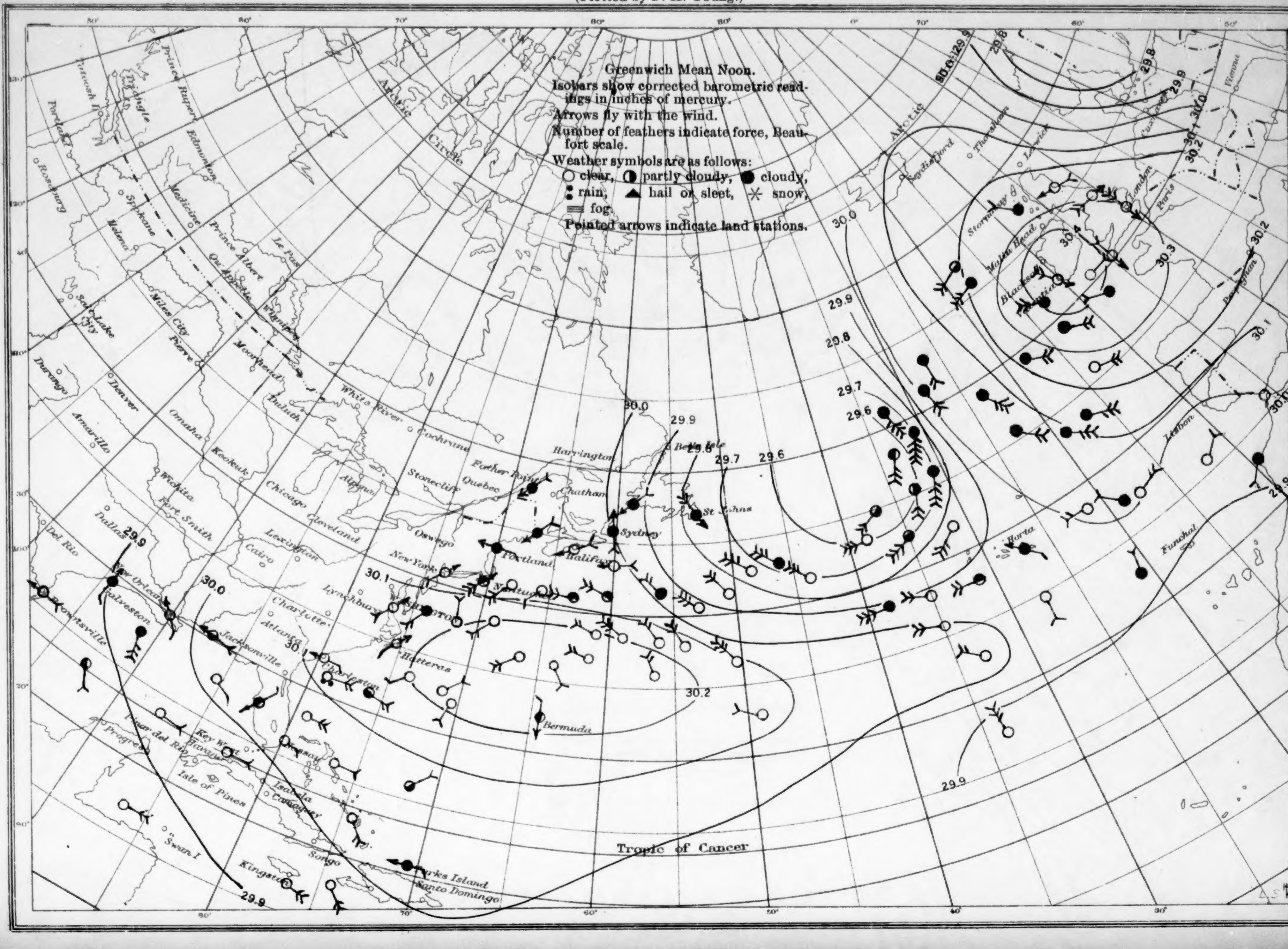

Chart XI. Weather Map of North Atlantic Ocean, June 11, 1920.

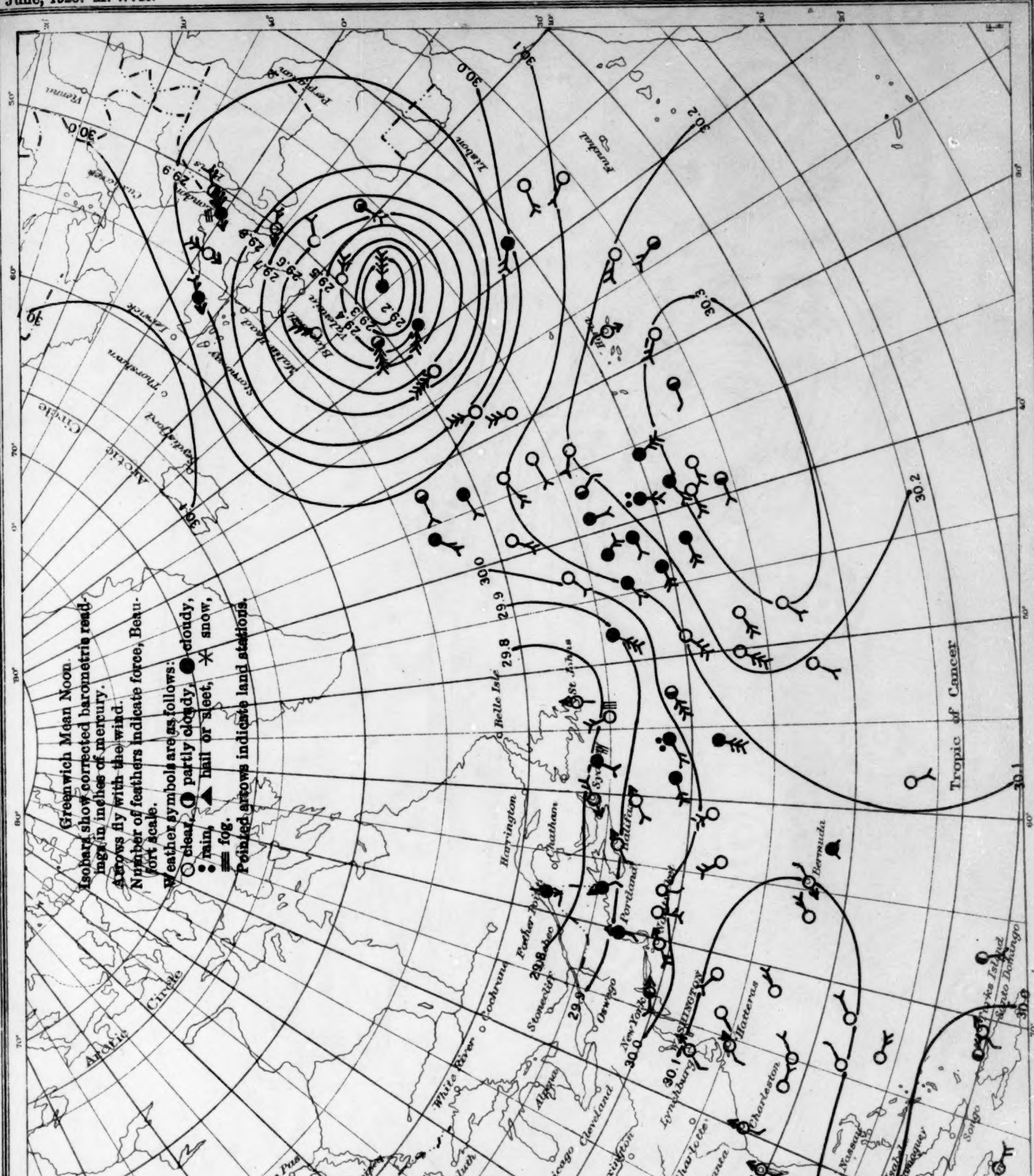

Chart XI. Weather Map of North Atlantic Ocean, June 11, 1920.
(Plotted by F. A. Young.)

Chart XII. Weather Map of North Atlantic Ocean, June 28, 1920.

(Plotted by F. A. Young.)